FACTORS INFLUENCING CHINOOK SALMON SPAWNING DISTRIBUTION IN THE TOGIAK RIVER, ALASKA

By

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Abstract

Salmonids are heavily dependent on specific habitat characteristics for survival, yet few studies in Alaska have examined the relationship between habitat and spawning distribution, using remote sensing approaches. To better understand the relationship between Chinook Salmon *Oncorhynchus tshawytscha* spawning distribution and environmental variables like habitat type (e.g., run, riffle, pool), temperature, and proximity to channel islands, optical and thermal imagery were collected on the Togiak and Ongivinuk rivers in southwest Alaska. Object-based image analysis was used to classify and quantify habitat types, while thermal characteristics and the proximity of spawning locations to channel islands were determined in a GIS framework. Object-based image analysis was useful for classifying habitat and may provide a better alternative to pixel-based image analysis. However, rule sets were nontransferable and inconsistent among river reaches, and caution should be taken when these methods are used on large river sections. Chinook Salmon showed a preference for spawning in river runs, 80% of fish spawned in water temperatures between 8.6° and 9.4°C, and nearly 61% of Chinook Salmon spawned within 100 m of a channel island. This study provided a baseline understanding of environmental correlates of spawning for Chinook Salmon at the northern extent of their range.

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General Introduction

Chinook Salmon *Oncorhynchus tshawytscha* is an important species for commercial, sport and subsistence fishing. Chinook Salmon are the largest of the Pacific salmon and live along the coasts of North America and Asia. Because of their large size and high-quality meat, in 2016, the mean ex-vessel price for Chinook Salmon statewide was $4.88/lb compared to the lowest price of $0.37/lb for Pink Salmon *O. gorbuscha* (ADFG 2018). Over 4.8 million pounds of Chinook Salmon with an approximate total value of $23.7 million were harvested in Alaska's commercial salmon fisheries (ADFG 2018). The estimated total subsistence harvest of salmon in Alaska in 2015, based on annual harvest assessment programs, was 860,809 fish, of which 49,225 (6%) were Chinook Salmon. The largest estimated subsistence harvests of Chinook Salmon in 2015 occurred in the Kuskokwim Management Area (19,437 salmon; 40%) followed by the Bristol Bay Management Area (13,874 salmon; 28%: Fall et al. 2018).

Unfortunately, almost all populations of Chinook Salmon in Alaska have experienced a decline in abundance and their abundance has remained low state-wide for more than a decade (ADFG Chinook Salmon Research Team 2013), which has caused fishery closures and other restrictions necessary for conservation. For example, in western Alaska, severe restrictions have occurred on both the Yukon and Kuskokwim rivers, affecting commercial and sport fishermen, as well as subsistence fishers who are dependent upon Chinook Salmon to feed their families (Sethi and Tanner 2014). Declines in populations may be driven by increased harvest rates, hatchery influences (e.g. disease, parasites, etc.), changing ocean conditions, marine mammal predation (Chasco et al. 2017), climate change (Crozier 2016), reduced genetic diversity (Johnson et al. 2018), habitat changes, or some combination of factors.

Interactions between habitat and Chinook Salmon behavior are important to the survival of juvenile Chinook Salmon. For example, the interaction between water temperature and spawn timing of adult salmon impacts juvenile survival because the date at which they spawn and ambient water temperature are the primary mechanisms controlling offspring emergence (Gilhousen 1990; Quinn and Adams 1996; Quinn et al. 2000). Offspring that emerge earlier or later than the optimal time for a given population may have several disadvantages (Weber Scannell 1992). As a result, spawn timing of specific populations is an adaptation to local thermal conditions and food availability; good spawn timing equates to increased rates of fry survival and vice versa. Because spawning success is closely tied to habitat variables, many researchers are interested in studying spawning habitat.

Another example of an interaction between habitat and Chinook Salmon behavior is the type of habitat chosen for spawning. Chinook Salmon tend to spawn in specific areas of rivers, ignore other areas that superficially appear similar (Vronskiy 1972), and spawn consistently in the same areas year after year (Klett et al. 2013). It is thought that the distribution of runs, riffles, pools, and channel complexity are factors related to preferred salmonid spawning locations (Torgersen et al. 2004). Chinook Salmon tend to spawn in pool-riffle habitats, which frequently occur in areas with alluvial deposits (Groot and Margolis 1991; Torgersen et al. 1999; Hamann et al. 2013). Additionally, Chinook Salmon redd clusters tend to occur in areas with complex channel patterns, rather than in areas where the channel is straight and simple (Geist and Dauble 1998). Geomorphic features such as mid-channel islands increase channel complexity, and large gravel bars consisting of alluvial deposits associated with these islands are important for Chinook Salmon spawning. Chinook Salmon prefer to spawn in these areas because they typically have upwelling or downwelling that creates interstitial flow, also known as hyporheic flow, through bed material (Brunke and Gonser 1997; Visser 2000) on the upstream and downstream portions of a channel island. Chinook Salmon prefer to spawn in areas of hyporheic flow (Visser 2000), likely because they moderate temperatures and flow regimes (Brunke and Gonser 1997) and provide consistent oxygenation of eggs (Groot and Margolis 1991).

Traditional approaches to studying salmon habitat are often time consuming, expensive, and difficult to apply to other river systems. The Instream Flow Incremental Methodology (IFIM) has been commonly used since 1976 (Bovee 1982) and is implemented using the Physical HABitat SIMulation (PHABSIM) computer model, which can be used to predict spawning habitat availability (Shirvell 1989). These models rely on data collected in the field, including depth, velocity, and substrate type, and can require a visual examination of channel characteristics collected at numerous reaches throughout a study area. Because this approach requires in-stream measurements, these data can be difficult to collect in large, fast-moving, and turbid rivers where it is not possible to wade the channel width or see and measure the substrate composition of the river bed. However, remote sensing and Geographic Information Systems (GIS) techniques have been used to classify salmonid habitat at the landscape level (Geist and Dauble 1998; Mertes 2002; Torgersen et al.1999; Torgersen et al. 2004). Optical and forward-looking infrared (FLIR) imagery can be collected simultaneously via aircraft, and provide high-resolution and spatially continuous information about stream channel morphology and stream temperature (Torgersen et al. 2004).

One method to identify and quantify habitat types is to collect optical imagery and classify the imagery using either pixel-based image analysis or object-based image analysis. Pixel-based software analyzes the spectral properties of every pixel, and results can be obtained with a supervised classification, an unsupervised classification, or a combination of the two (Van de Voorde et al. 2004; Enderle and Weih Jr. 2005). However, the pixel-based method can result in a “salt and pepper” effect which affects the accuracy of the classification (Weih Jr. and Riggan

Jr. 2010). The “salt and pepper” effect is caused by high local spatial heterogeneity between neighboring pixels and results in similar classes being classified as separate classes, despite being similar (Kelly et al. 2011). Object-based image classification with eCognition® software can analyze both the spectral and spatial properties of pixels and uses a segmentation process that groups similar pixels together, and these groups of pixels are then identified as objects (Ridgeway 2006). These objects are later classified into specific categories, which may be more accurate than traditional pixel-based methods (Hay and Castilla 2006; Weih Jr. and Riggan Jr. 2010).

An additional tool for assessing habitat is to collect FLIR imagery. FLIR imagery has been used to monitor and assess salmonid thermal habitat in several rivers and streams in Oregon, Washington, Idaho (Torgersen et al. 1996; Torgersen et al. 1999) and Quebec, Canada (Dugdale et al. 2013). Overall, optical and thermal imagery collection along with GIS can provide a way to understand factors influencing spawning distribution and can provide a means for assessing patterns of fish distribution at the landscape level (Torgersen et al. 2004).

This study was conducted within the Togiak River drainage in southwest Alaska, which partially lies within the Togiak National Wildlife Refuge (TNWR). The Togiak River supports healthy populations of all five species of Pacific salmon *Oncorhynchus spp.*, Arctic Char *Salvelinus alpinus*, Arctic Grayling *Thymallus arcticus*, Dolly Varden *S. malma*, and Rainbow Trout *O. mykiss*. The Togiak River frequently provides the second largest harvest of Chinook Salmon for sport (Dye and Schawnke 2012), commercial (Sands 2012; Elison et al. 2018), and subsistence fisheries (Elison et al. 2018) in Bristol Bay, behind the Nushagak River. In the 2008

Togiak village subsistence survey, salmon made up the largest portion of usable wildlife resource harvested (35%), which was estimated at 106 lbs of salmon per capita, with Chinook Salmon consisting of 50.2 lbs per capita (Fall et al. 2018).

The Togiak River has experienced declines in the number of adult Chinook Salmon being harvested, and it is assumed that this decline reflects decreasing abundance (Heard et al. 2007). Reasons for the decline are currently unknown; however, traditional ecological knowledge indicates that the riverine environment is changing. Specifically, tribal elders indicate that tributaries are experiencing lower water levels and the spawning distribution of Chinook Salmon has shifted from tributaries to the mainstem, with more Chinook Salmon spawning in the mainstem than in tributaries (Pete Abraham, personal communication 2011).

To provide information about habitat characteristics of the Togiak River drainage, optical and thermal imagery was collected and analyzed on approximately 36 rkm in the Togiak and Ongivinuk rivers. The goal of chapter one was to describe and quantify habitat in the Togiak and Ongivinuk rivers. The objectives were to (1) quantify the availability of three primary classes as runs, riffles, and pools, with two secondary classes as shadows and shallow water; (2) assess the accuracy of object-based image analysis for delineating these habitat classes; and (3) examine thermal characteristics of the river. The goal of chapter two was to understand environmental correlates of spawning distribution of Chinook Salmon in the Togiak and Ongivinuk rivers. The objectives were to (1) identify where Chinook Salmon spawn; (2) identify habitat type preferences for spawning (e.g. runs, riffles, pools, shallow water, and shadows); and (3) identify thermal preferences of Chinook Salmon spawning.

References

ADFG (Alaska Department of Fish and Game). 2018. Information by fishery. Commercial salmon catch, effort and value. http://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.salmoncatch

ADFG (Alaska Department of Fish and Game) Chinook Salmon Research Team. 2013. Chinook Salmon stock assessment and research plan 2013. ADFG Division of Sport Fish and Commercial Harvest. Special Publication No. 13-01.

Bovee, K. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Fort Collins, Colorado: USFWS.

Brunke, M., and T. Gonser. 1997. The ecological significance of exchange processes between rivers and groundwater. Freshwater Biology, 37:1–33.

Chasco, B., I.C. Kaplan, A. Thomas, A. Acevedo-Gutiérrez, D. Noren, M.J. Ford, M.B. Hanson, J. Scordino, S. Jeffries, S. Pearson, K.N. Marshall, E.J. Ward. 2017. Estimates of Chinook salmon consumption in Washington State inland waters by four marine mammal predators from 1970 to 2015. Canadian Journal of Fisheries and Aquatic Sciences 74(8): 1173–1194.

Crozier, L. 2016. Impacts of climate change on salmon of the Pacific northwest. Seattle, Washington: NOAA.

Dugdale, S., N. Bergeron, and A. St-Hilaire. 2013. Temporal variability of thermal refuges and water temperature patterns in an Atlantic salmon river. Remote Sensing of Environment 136:358–373.

Dye, J., and C. Schawnke. 2012. Report to the Alaska Board of Fisheries for the recreational fisheries of Bristol Bay, 2010-2012. ADFG.

Elison, T., P. Salomone, T. Sands, G. Buck, K. Sechrist, and D. Koster. 2018. 2017 Bristol Bay management report. Fishery Management Report No. 18-11. ADFG.

Enderle, D., and R. Weih, R. Jr. 2005. Integrating supervised and unsupervised classification methods to develop a more accurate land cover classification. Journal of the Arkansas Academy of Science, 59:65–73.

Fall, J.A., A. Godduhn, G. Halas, L. Hutchinson-Scarbough, B. Jones, E. Mikow, L.A. Sill, A. Trainor, A. Wiita, and T. Lemons. 2018. Alaska subsistence and personal use salmon fisheries 2015 annual report. Technical Paper No. 440. ADFG.

Geist, D., and D. Dauble. 1998. Redd site selection and spawning habitat use by fall Chinook Salmon: The importance of geomorphic features in large rivers. Environmental Management 22(5):655–669.

Gilhousen, P. 1990. Prespawning mortalities of sockeye salmon in the Fraser River system and possible causal factors. Vancouver, B.C.: International Pacific Salmon Fisheries Commission. Retrieved from http://www.psc.org/download/48/ipsfc-bulletins/2392/ipsfcbulletinxxvi.pdf

Groot, C., and L. Margolis. 1991. Pacific salmon life histories. Vancouver: UBC Press.

Hamann, E., B. Kennedy, D. Whited, and J. Stanford. 2013. Spatial variability in spawning habitat selection by Chinook Salmon (*Oncorhynchus tshawytscha*) in a wilderness river. River Research and Applications 30(9):1099–1109.

Hay, G., and G. Castilla. 2006. Object-based image analysis: strengths, weaknesses, opportunities, and threats (SWOT). OBIA, 2006: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Retrieved from https://pdfs.semanticscholar.org/0c07/7b867fea1e4f1ff1dc2e9a9dc1b8b9d87932.pdf

Heard, W.R., E. Shevlyakov, O.V. Zikunova, R.E. McNicol. 2007. Chinook Salmon – Trends in abundance and biological characteristics. North Pacific Anadromous Fish Commission Bulletin No. 4:77–91.

Johnson, B., B. Kemp, and G. Thorgaard. 2018. Increased mitochondrial DNA diversity in ancient Columbia River basin Chinook Salmon *Oncorhynchus tshawytscha*. PLOS ONE, 13(1).

Kelly, M., S.D. Blanchard, E. Kersten, and K. Koy. 2011. Terrestrial remotely sensed imagery in support of public health: new avenues of research using object-based image analysis. Remote Sensing 3:2321–2345.

Klett, K., C. Torgersen, J. Henning, and C. Murray. 2013. Spatial consistency of Chinook Salmon redd distribution within and among years in the Cowlitz River, Washington. North American Journal of Fisheries Management 33(3):508–518.

Mertes, L. 2002. Remote sensing of riverine landscapes. Freshwater Biology 47(4):799–816.

Quinn, T.P., and D.J. Adams. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology *77*(4):1151–1162.

Quinn, T.P., M.J. Unwin, and M.T. Kinnison. 2000. Evolution of temporal isolation in the wild: genetic divergence in timing of migration and breeding by introduced Chinook Salmon populations. Evolution 54(4):1372–1385.

Ridgeway, J. 2006. Object-oriented approaches to mapping channel habitat on the lower Congo River. Master's Thesis. The University of Georgia.

Sands, T. 2012. Overview of the Bristol Bay salmon fishery 2010-2012, a report to the Alaska Board of Fisheries. ADFG.

Sethi, S., and T. Tanner. 2014. Spawning distribution and abundance of a northern Chinook Salmon population. Fisheries Management and Ecology 21(6):427–438.

Shirvell, C. 1989. Ability of PHABSIM to predict Chinook Salmon spawning habitat. Regulated Rivers: Research and Management 3(1):277–289.

Torgersen, C., R. Gresswell, and D. Bateman. 2004. Pattern detection in stream networks: quantifying spatial variability in fish distribution. In Second International Symposium on GIS/Spatial Analyses in Fishery and Aquatic Sciences:405–420.

Torgersen, C., N. Poage, M. Flood, D. Norton, and B. McIntosh. 1996. Airborne thermal remote sensing of salmonid habitat for restoration planning in Pacific Northwestern watersheds. In Watershed 96 Conference. Alexandria, Virginia: Water Environment Federation.

Torgersen, C., D. Price, H. Li, and B. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of Chinook Salmon in Northeastern Oregon. Ecological Applications 9(1):301.

Van de Voorde, T., W. De Genst, F. Canters, N. Stephenne, E. Wolff, and M. Binard. 2004. Extraction of land use/land cover-related information from very high-resolution data in urban and suburban areas. Remote Sensing in Transition, Proceedings of the 23rd Symposium of the European Association of Remote Sensing Laboratories. Retrieved from http://www.vub.ac.be/spider/publications/paper-earsel-2003.pdf

Visser, R. 2000. Using remotely sensed imagery and GIS to monitor and research salmon spawning. a case study of the Hanford Reach fall Chinook (*Oncorhynchus tshawytscha*). Pacific Northwest National Laboratory.

Vronskiy, B. 1972. Reproductive biology of the Kamchatka River Chinook Salmon [*Oncorhynchus tshawytscha* (Walbaum)]. Journal of Ichthyology 12:259–273.

Weber Scannell, P. 1992. Influence of temperature on freshwater fishes: a literature review with emphasis on species in Alaska. ADFG Habitat Division.

Weih, Jr. R., and N. Riggan, Jr. 2010. Object-based classification vs. pixel-based classification: comparative importance of multi-resolution imagery. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Retrieved from http://www.isprs.org/proceedings/xxxviii/4-c7/pdf/Weih_81.pdf

Chapter 1: Object-Based Classification and Thermal Variability in the Togiak River, Alaska

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Abstract

Fisheries habitats are inherently complex with innumerable characteristics that influence several aspects of fish biology and ecology. One group of fishes that is heavily reliant on specific habitat types is salmonids, but few studies at the northern end of their range in Alaska have quantified available habitat due to challenges associated with collecting data in remote places. To determine if object-based image analysis was a viable method for classifying habitat and to establish baseline information about habitat types and thermal characteristics on an important salmonid river, remotely sensed optical and thermal imagery was collected on approximately 36 rkm on the Togiak and Ongivinuk rivers in southwest Alaska. Object-based image analysis was used to classify and quantify runs, riffles, pools, and thermal characteristics of the rivers were examined in a GIS framework. Throughout the study area, runs compromised 55% of the total habitat, followed by shallow water at 26%, pools at 12%, shadows at 4% and riffles at 3%. Accuracy of image classification varied between 68% and 74% in the three reaches of the study area. The majority of temperatures were between 8.6°–9.8°C in each of the three reaches. Object-based image analysis was useful for classifying habitat and may provide a better alternative to pixel-based image analysis. However, rule sets were nontransferable, inconsistent, and time consuming to develop, and caution should be taken when they are used on large river

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study areas. Monitoring water temperature is important in a changing climate, and this study provided baseline information for an important Chinook Salmon river in southwest Alaska, against which future changes in water can be compared.

Introduction

Fish habitats are typically complex and can affect the abundance and distribution of fishes. Habitat can be defined by a broad range of characteristics, and characteristics can be examined at a range of scales, from large to small. Macrohabitat refers to a longitudinal portion of stream within which physical and/or chemical conditions influence the suitability of an entire stream segment. Mesohabitat refers to a discrete area of stream defined by the channel geometry with similar physical characteristics (e.g. slope, width, depth, substrate size, etc.) and is generally labeled as runs, riffles, pools, etc. (Hawkins et al. 1993; Martinez and Sims 2012). Microhabitat refers to the physiochemical characteristics, such as depth, velocity, substrate size, and cover, of small, localized areas used by an aquatic organism for specific behaviors (e.g. spawning). Finally, total habitat is an aggregation of available wetted area conditioned by the interaction of microhabitat and macrohabitat characteristics. Changes in habitat at any scale can positively or negatively influence fish populations; therefore, it may be necessary to study and monitor habitat to effectively manage fisheries.

Remote sensing image acquisition and analyses are becoming more common for examining micro- to macro-scale habitat characteristics of riverine landscapes (Torgersen et al. 1996; Mertes 2002). One method to examine meso- and macrohabitat characteristics is to collect optical imagery and to classify the imagery using either pixel-based or object-based image analyses. Pixel-based software analyzes the spectral properties of every pixel, which is then classified through supervised classification, unsupervised classification, or a combination of the two (Weih Jr. and Riggan Jr.

2010). An alternative approach is object-based image classification that analyzes both the spectral and spatial properties of pixels and uses a segmentation process that groups similar pixels together. These groups of pixels are then identified as objects (Ridgeway 2006) and are later classified into specific categories (e.g. runs, riffles, pools). This approach is believed to be more accurate than traditional pixel-based methods (Hay and Castilla 2006; Weih Jr. and Riggan Jr. 2010). Regardless of the method, an 85% accuracy threshold (Foody 2002), which is determined by comparing assigned habitat classes to known habitat classes, is used. An accuracy rate below this threshold is thought to result from an approach that has limited utility for habitat classification.

In addition to understanding habitat characteristics using optical properties, thermal properties may also be examined with remote sensing. Forward-looking infrared (FLIR) data provides spatially continuous thermal imagery and is used to monitor and assess habitat in rivers and streams (Torgersen et al. 1996; Hamman et al. 2013). This approach has been used in several places, including Alaska (Smikrud et al. 2008; Woll et al. 2011). FLIR imagery acquired via aircraft has proven effective for identifying and mapping microhabitat–scale thermal heterogeneity associated with hyporheic flow, discharge patterns, and geothermal inputs within a river channel (Burkholder et al. 2008; Cardenes et al. 2008; Dunckel et al. 2009). At this scale, groundwater springs and cold-water seeps may be visible in larger river sections, and patterns in both lateral and longitudinal thermal variations can be observed (Carbonneau and Piégay 2012).

One group of fishes that is heavily reliant on specific habitat characteristics that have been studied by remote sensing is salmonids (Torgersen et al. 1996; Hamann et al. 2013; Monk et al. 2013). These studies have covered a wide range of scales from 12 km (Smikrud et al. 2008) to 1,600 rkm (Torgersen et al. 1996). Optical imagery has been used to examine the characteristics of adult salmon spawning habitat (Torgersen et al. 2004; Hamann et al. 2013) and juvenile salmon rearing habitat (Smikrud et al. 2008; Woll, et al. 2011). Additionally, FLIR imagery has been used to assess stream temperatures and identify warm-water and cold-water refugia (Torgersen et al. 1996; Wirth et al. 2012; Monk et al. 2013).

In Alaska, Chinook Salmon is an important species in commercial, sport and subsistence fisheries. Chinook Salmon abundance has declined across multiple Alaskan stocks, resulting in closures or restrictions in commercial, sport, and subsistence fisheries. In the Yukon River drainage since 2007, restrictions have included reduced fishing periods, closures, and gear restrictions (Estensen et al. 2018); and in the Kenai River in 2018, restrictions limited sport fishermen to only catch-and-release of Chinook Salmon (ADFG 2018). In Bristol Bay in western Alaska, the Togiak River frequently supports the second largest harvest of Chinook Salmon, in sport (Dye and Schawnke 2012), commercial (Sands 2012; Elison et al. 2018), and subsistence fisheries (Elison et al. 2018). However, the Togiak River has experienced declines in the number of adult Chinook Salmon being harvested, and it is assumed that this decline reflects decreasing abundance (Heard et al. 2007).

The reasons for the Chinook Salmon stock declines are currently unknown; however, local knowledge indicates that the riverine environment is changing (Pete Abraham, personal communication 2011). Specifically, tributaries are thought to be experiencing lower water levels, and as a result, the spawning distribution of Chinook Salmon has shifted from tributaries to the mainstem. However, there is limited comprehensive scientific data about habitat characteristics of the Togiak River system to complement local knowledge.

To understand habitat characteristics in the Togiak River watershed, we conducted a remote sensing study to test a new approach for classifying habitat and to establish an affordable and effective baseline against which future quantitative comparisons can be made. The objectives were to (1) quantify the availability of three primary habitat classes as runs, riffles and pools, and two secondary classes as shadows and shallow water, (2) assess the accuracy of object-based image analysis for delineating these habitat classes, and (3) examine thermal characteristics of the river. Few remote sensing projects that utilize both optical and thermal imagery have been conducted in Alaska, which is at the northern edge of the range of Chinook Salmon. However, because habitat is important to both juvenile and spawning adult Chinook Salmon, and can influence population abundance, it is important to quantify available habitat and assess thermal variability in streams.

Methods

Study Site

This study was conducted within the Togiak River drainage in southwest Alaska, which partially lies within the Togiak National Wildlife Refuge (TNWR; Figure 1.1). The Togiak River begins at the outlet of Togiak Lake and flows 93 rkm to Togiak Bay. It is surrounded by the Wood River Mountains to the east and the Ahklun Mountains to the west. The watershed is made up of nine major lakes, five major tributaries, and encompasses 5,178 km^2 (Tanner and Sethi 2014). Within the Wilderness Area, where the study occurred, a single main channel with occasional small islands, deep holes, and gravel point bars characterize the river. River substrate size ranges from sand to large cobble with medium size boulders (USFWS 2009). Two reaches, one each in the upper and lower portions of the mainstem Togiak River, were selected for analyses in this study, and are further referred to as lower mainstem and upper mainstem.

A portion of the Ongivinuk River, the uppermost tributary in the Togiak River watershed, was also included as the third reach for analyses in the study. The Ongivinuk River is a clear-water tributary (Hetrick et al. 2004), and it is one of the most accessible tributaries during low water. The Ongivinuk River flows about 50 rkm from Ongivinuk Lake before emptying into the Togiak River, 70 km upstream from Togiak Bay (Hetrick et al. 2004). The river is characterized by a single main channel with numerous deep holes and gravel point bars (USFWS 2009).

Aerial Survey and Image Acquisition

An aerial survey of the three study reaches was conducted on August 9, 2012. The flight was selected to take advantage of low-flow conditions on the Togiak River during late summer. Image acquisition occurred in the late morning under clear sky and low wind conditions. Optical and thermal imagery were obtained in Nadir-looking aerial photos that were acquired using an USFWS-operated Bushhawk Found aircraft with camera ports in the aircraft floor (Figure 1.2). A Nikon D700 digital camera was used to collect optical images in the visible spectrum, and a FLIR A320 automation series camera was used to collect thermal infrared imagery (TIR) in the broadband (7.5–13.0 μm) region. Both cameras were focused to infinity and level mounted with a Cross Bow Inertial Measurement Unit (IMU) to record the aircraft perturbations (roll, yaw, and pitch). An external Garmin Global Positioning System (GPS) antenna placed on the aircraft windscreen provided the locational attributes. The time records of the GPS and IMU units were synchronized so that each optical and FLIR image was exported with accurate information on image geometry and image location.

Flying at an elevation of approximately 1 km above ground level at a velocity of 200 km/h, the system collected optical and thermal images at 10 cm and 1 m resolution, respectively. Optical images had ~40% side lap and ~70% forward lap to facilitate generating a comprehensive mosaic product. Thermal images were acquired as continuous videos with a higher forward lap, and only ~20% side lap. The data acquisition started at 10:56 on the lower mainstem, continued to the Ongivinuk River, and concluded at 13:12 after surveying the upper mainstem.

Ground Control Points

Ground control points were collected in conjunction with aerial image acquisition to further rectify the geolocation of aerial images (Figure 1.3). Low emissivity space blankets (~2 m x 2 m) were placed on the ground and their location noted using a differential GPS measurement. These reflective blankets showed up prominently on the optical images as bright spots and on thermal images as a cold dark point, assisting to verify the absolute location of the final image mosaics.

Because atmospheric conditions affect the temperature readings recorded during the acquisition of FLIR imagery, calibrations need to be applied to the images to produce accurate depictions of temperature. To calibrate FLIR imagery, water temperature, air temperature, humidity, and wind speed measurements were collected simultaneously with the FLIR images. To record water temperature, two HOBO® water temperature Pro V2 data loggers were deployed. One of the loggers was placed in the lower Togiak River on August 7, 2012. The second was placed in the Ongivinuk River on August 8, 2012. The loggers were set to record water temperature every twenty seconds. To record air temperature and relative humidity, two HOBO® Temperature/Relative Humidity Pro V2 data loggers, were deployed. The loggers were set to record air temperature and relative humidity every 40 seconds. The first was deployed near the lower Togiak River on August 7, 2012 and the second was placed near the Ongivinuk River on August 8, 2012. Additionally, during the flight on August 9, 2012, wind speed and relative humidity were recorded with a Kestrel 0830 pocket weather meter. The HOBO® sensors also showed up in optical images, providing additional ground control points for validating the spatial accuracy of the image products (Figure 1.3).

Habitat Classification

Agisoft PhotoScan (version 0.9.0) was used to generate mosaics of each study site from hundreds of individual optical images that already had locational attributes from the GPS unit. Agisoft PhotoScan detects the same feature on at least two adjacent images and uses a 3D modeling solution to automatically generate seamless mosaics (Figure 1.4; Agisoft PhotoScan 2016). The uncontrolled mosaics had high geometric fidelity, and the geolocation was further refined to ±20 cm accuracy using the measured GCPs. Approximately 36 rkm of mosaics were created, roughly 10 rkm in each of the lower mainstem and Ongivinuk River, and 16 rkm in the upper mainstem.

Before the object-based classification was conducted, the outline of the riverbank was digitized using ArcGIS to mask out non-water areas. This was done to decrease the processing time required for each scene, to simplify the interpretation of results, and to ensure that any thresholds calculated were based on water pixels alone. Next, each site (lower mainstem, upper mainstem, and Ongivinuk River) was divided into smaller areas, to further decrease the processing time required for each section.

Trimble eCognition® Developer version 8.9.0 (©2014 Trimble Geospatial Imaging) was used to develop the workflow (rule set) to classify river habitat as runs, riffles and pools. The general morphology of runs is a consistent channel shape, a well-defined thalweg, and a moderate to fast current with minimal surface turbulence. Riffles exhibit a variable channel shape and are shallow with fast-moving water and substantial surface turbulence. Finally, pools are deep, have slow to fast moving water, are generally bowl shaped, and have minimal surface turbulence (Woll et al. 2011; West Virginia Department of Environmental Protection 2012). In each study area section, the first step was to perform a multiresolution segmentation on the red, green, and blue layers of the image, splitting the image into smaller objects to maximize differences in color between individual objects. A scale factor of 40 was used for the initial object size. The higher the scale factor, the larger each object will be in the segmentation. The value of shape was 0.2. A low shape value meant more value was placed on color. A compactness parameter of 0.9 was used to create objects that were round instead of long and thin. These choices tended to keep the individual objects relatively smooth, while accounting for natural shapes seen in the image.

The identified objects were assigned to three primary classes (runs, riffles, and pools; Figure 1.5; Table 1.1) and two secondary classes (shadows and shallow water), based on an iterative approach that incorporated elements of texture, size, and tone. An artifact of remote sensing are shadows caused by overhanging vegetation. Unfortunately, shadows often mask near-shore spectral and textural variations visible in optical imagery; and therefore, need to be classified separately, even though shadows are not necessarily a true habitat class.

To distinguish between runs and pools, the normalized difference between blue/green bands (NDBG) above zero was used. Runs typically appear more greenish, while pools tend to be more blue. Because this is a run-dominated system, this classification is more a distinction between deeper and shallower stretches of runs, and not necessarily true 'pools' as indicated by deep, slow moving water:

$$NDBG = {}^{Blue - Green}/_{Blue + Green} > 0 \qquad 1.1$$

The riffle category used the most variables to assign to a class. A high brightness value relative to the mean for the scene indicated light reflecting off of surface waves. Next, a Gray

Level Co-occurrence Matrix (GLCM) was computed. GLCM Homogeneity is a measure of roughness of an image object. Because riffle patches tend to appear rough, riffles tend to have lower GLCM Homogeneity values than other sections of the river. Similar GLCM Contrast values in all bands, high values GLCM Entropy in the Blue band, and low values of GLCM Homogeneity compared to the rest of the scene were all criteria used to classify riffles.

To classify shadows, only objects that bordered the edge of the river were considered, since shadows were unlikely to occur in the middle of the river. A standard RGB (Red, Green, Blue) to IHS (Intensity, Hue, Saturation) transformation and mean brightness were calculated (Definiens Developer 2012). The mean brightness and mean intensity were used because these show the difference between light and dark features in the scene better than straight RGB values.

Shallow water was classified based on the relative redness of each object. Objects with higher normalized difference red values (NDRV) tend to appear more brown, which is indicative of shallow water (as opposed to deeper water, which appears more blue/green):

$$NDRV = {}^{Blue + Green - Red}\!/_{Blue + Green + Red} \qquad 1.2$$

Finally, smaller features that were surrounded by a different class were classified and depending on the class type, smaller features were merged into the surrounding class. For example, runs tend to be larger features, and it would not be expected to find small (< 10 m^2) runs surrounded by a large area of riffles. Likewise, shadows that do not connect to the edge of the river would not be expected. To finalize the data products, polygons were manually edited to line up with previously split scenes. The final classification was exported to both GeoTiff and ESRI shapefile formats for further analysis (Figure 1.6).

To assess the accuracy of the classification scheme, a random selection of 100 points was used for each class in the lower mainstem and compared to manually classified points in the automated results. For the upper mainstem and Ongivinuk, not all classes were sufficiently represented to warrant such a large selection for each class, so only 73 points from pools and 27 from shadows for the Ongivinuk, and 20 points from pools and 40 points from shadows in the upper mainstem were used. This yielded a total of 1260 sample points and using the reference data, each classified object was put into its true category, creating a confusion matrix. This used verified classes and compared them with predicted values from the classification model (Table 1.2).

Cohen's Kappa was used as an overall measurement of accuracy that is based on the agreement of the confusion matrix compared to agreement by chance (Congalton and Green 1999):

$$\kappa = \frac{p_0 - p_e}{1 - p_e} = 1 - \frac{1 - p_0}{1 - p_e} \qquad 1.3$$

where $p_{0=}$ observed agreement (accuracy) and

$p_{e=}$ hypothetical probability of chance agreement:

$$p_{e=} \frac{1}{N^2} \sum_K n_{K2}\, n_{K2} \qquad 1.4$$

Values can range from -1 to +1, a value of 0 represents the amount of agreement that can be expected from random chance, +1 represents the software accurately classified each object every time, and -1 represents the software never accurately classified an object.

Thermal Classification

Using a built-in algorithm that uses flying height, ambient temperature, and atmospheric humidity at the time of flight, ThermaCAM Researcher Pro 2.10 was used to calibrate remotely sensed temperatures. The software also used a second in-built algorithm based on an inversion of Planck's function to convert recoded signals to surface temperature values, using a user-supplied emissivity value (FLIR Systems 2006). For this study, we used a constant and high emissivity value of 0.98 for all sites as our main interest was in studying the river water, and water acts nearly like a blackbody.

The individual files exported from the ThermaCAM software were imported into EnsoMOSAIC, an integrated photogrammetric software package, and were used to create an image mosaic product for the thermal imagery. The software efficiently handled the FLIR image formats and could run robust automated aerial triangulations to generate seamless mosaic products.

ArcGIS ArcMap 10.3.1 was used to examine thermal variability in each section (Figure 1.7). A thermal threshold of 12.5°C was used to exclude land and vegetation; temperature values less than that were classified as water. Water in the thermal mosaics was color-coded according to temperature and classified into temperature bins ranging from 7.4° to 10.6°C. The first bin was 7.4°–8.2°C and the remaining bins were in 0.4°C increments, which is twice the temperature sensitivity of the thermal camera (0.2°C). Pixel counts were used to quantify each thermal class, and the weighted average was calculated for the upper mainstem, lower mainstem, and Ongivinuk River sections using:

$$\frac{\sum(Temperature * Pixel\ Count)}{Total\ Pixel\ Count} \tag{1.5}$$

Results

Habitat Classification

Throughout the entire study area, runs compromised 55% of the total aquatic habitat, followed by shallow water at 26%, pools at 12%, shadows 4%, and riffles at 3% (Figure 1.8).

Runs were the most prevalent class in both mainstem sections, with the upper section consisting of approximately 55% runs, while the lower section consisted of approximately 63% runs. The remaining aquatic habitat in the mainstem sections consisted of shallow water (upper: 22% and lower: 34%) and pools (10% and 6%, respectively). In the Ongivinuk River, pools were the dominant class at approximately 36%, followed by runs at 32% and shallow water at 16%.

Overall accuracy for image classification was highest for the lower mainstem (74%) and lowest for the upper mainstem (68%), with the Ongivinuk in between at 71.8%. Cohen's Kappa showed a similar pattern of accuracy (0.67, 0.63, and 0.56 for lower mainstem, Ongivinuk, and upper mainstem, respectively). In general, the habitat classes of shallow water, runs, and riffles were over-classified (classes were predicted more than they occurred), and pools and shadows were under-classified (Table 1.2).

Thermal Classification

During the flight over the three sections of the study area (10:56–11:45 lower mainstem; 11:55–12:25 Ongivinuk River; 12:25–13:12 upper mainstem), the average ambient temperatures were 21.2°C, 16.2°C, and 16.9°C, respectively, and humidity values were 52%, 75%, 70%, respectively. After images were calibrated, the majority of temperatures in all three subsections were 8.6°–9.8°C, with nearly 90% in this range in the lower mainstem and Ongivinuk River, and approximately 80% in the upper mainstem (Figure 1.9). The weighted average temperature in the lower mainstem and upper mainstem was 9.2°C, while it was 9.3°C in the Ongivinuk River.

Discussion

Object-based image analysis provided an alternative method to traditional pixel-based image analysis. Although this technique is not common in fisheries research, particularly in

Alaska, it appears to be promising for understanding salmonid habitat. Our approach relied on high-quality mosaics that allowed the smallest details to be observed, in conjunction with strong familiarity with the study area. This combination helped to develop a rule set that could be used to segment and classify the entire study area.

The accuracy of object-based habitat classification was well below the 85% accuracy threshold generally accepted for classification used in remote sensing (Foody 2002). Flight direction, sun angle, and light conditions can all affect the spectral properties of the imagery and create discrepancies in the classification, reducing accuracy (Woll et al. 2011). However, the flight occurred during excellent conditions (sunny, cloud free, minimal wind, and good flying height), which likely did not affect the overall accuracy assessment. Rather, our accuracy rate is very conservative and not directly comparable to most previous studies. This conservative approach results from only including aquatic habitat classes, which are challenging to delineate and classify. In contrast, accuracy assessments in previous studies rely on all habitat classes, including easily identifiable terrestrial classes like gravel bars and vegetation (Woll et al. 2011).

Additionally, it was not possible to develop a rule set that worked well for all three study sections. Considerable time was spent developing individual rule sets that ultimately were not transferrable to other sections of the river. Specifically, criteria used to classify habitat classes in the lower mainstem often did not work well in the upper mainstem section. This was likely because of differences in habitat characteristics, such as increased water clarity, depth, and a more stable channel in the upper mainstem compared to elsewhere. One notable example of incorrectly classified data was from the upper mainstem section. The substrate on the bottom was visible and therefore reflected more brown/red values and was classified as shallow water even though it was the deepest section in the watershed.

The Togiak River and the Ongivinuk River displayed a similar (9.2°C and 9.3°C) average weighted temperature. This is within the range of average August temperatures reported in previous years for the lower mainstem Togiak River (8.78–13.96°C; Swaim 2013). Interestingly, the Ongivinuk River was slightly warmer than both mainstem sections, despite the general assumption that tributaries are colder than river mainstems. Water temperatures in a river system is determined by the water's source (groundwater, snowmelt, rainfall, etc.), air temperature, amount of sunlight penetration, and water velocity. Perhaps the slight difference in temperature was a result of low-flow conditions on a sunny day.

In this study, remote sensing had clear advantages over a foot-based habitat survey because detailed imagery (both optical and thermal) for large areas were collected in a short amount of time (less than three hours for this study) and with high resolution (10 cm optical, 1 m FLIR). Even though a ground crew must place ground control points and in-stream temperature loggers, as well as record relative humidity, wind speed, and air temperature to validate and correct imagery, a purely foot-based survey would have been considerably more labor-intensive, time-consuming, and dangerous.

Conclusion

The main goal of this project, to establish baseline information about the habitat characteristics of the Togiak River system using a remote sensing approach, was successfully accomplished. The techniques developed in this study should be applicable to other Alaskan watersheds and could be used to gather additional information about remote rivers in Alaska. There is broad agreement within the river sciences that water temperatures in northern and temperate watersheds will increase (Dugdale et al. 2013), which will put aquatic resources at risk. By comparing current conditions with future projections, we can begin to assess the impacts of a changing climate.

Acknowledgements

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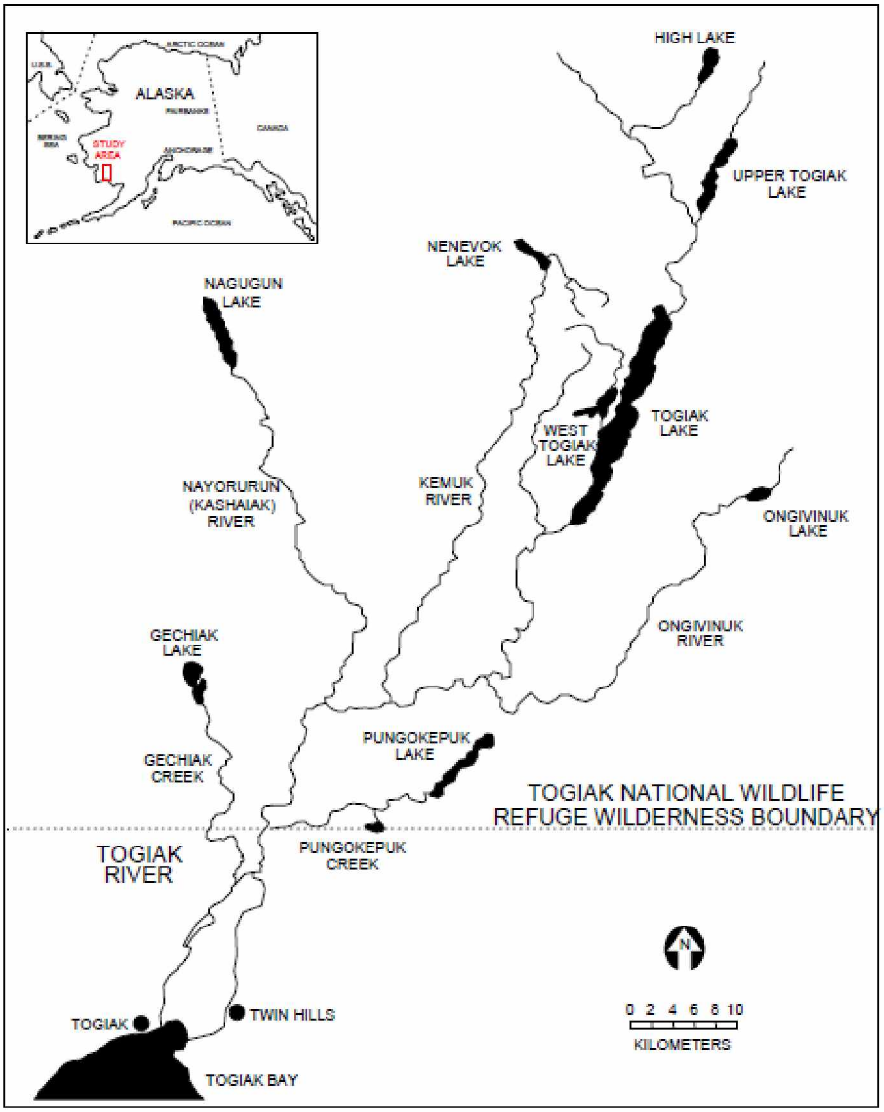


Figure 1.1: Map of Togiak River watershed in southwest Alaska, with prominent water bodies indicated (Tanner and Sethi 2014).

Figure 1.2: Bushhawk Found (left) and camera ports used to collect optical and thermal imagery over the Togiak and Ongivinuk rivers in southwest Alaska in August 2012. A) Digital Camera B) FLIR camera set up in belly panel.

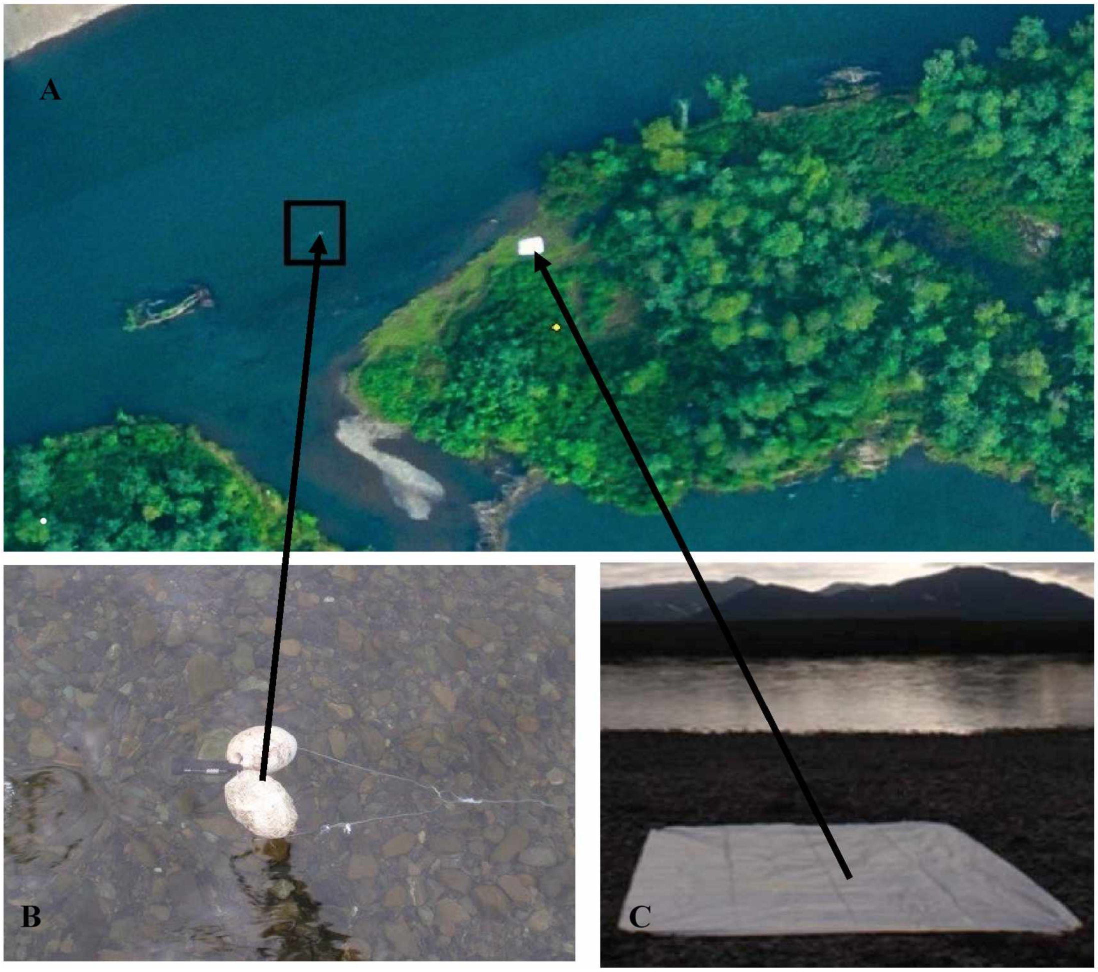


Figure 1.3: Ground control points (GCPs) used for correcting geolocation errors in the Togiak River watershed in southwest Alaska: A) GCPs are visible in the aerial photos; B) HOBO® thermistor deployed in shallow water; C) reflective tarp laid out on land near the edge of the river.

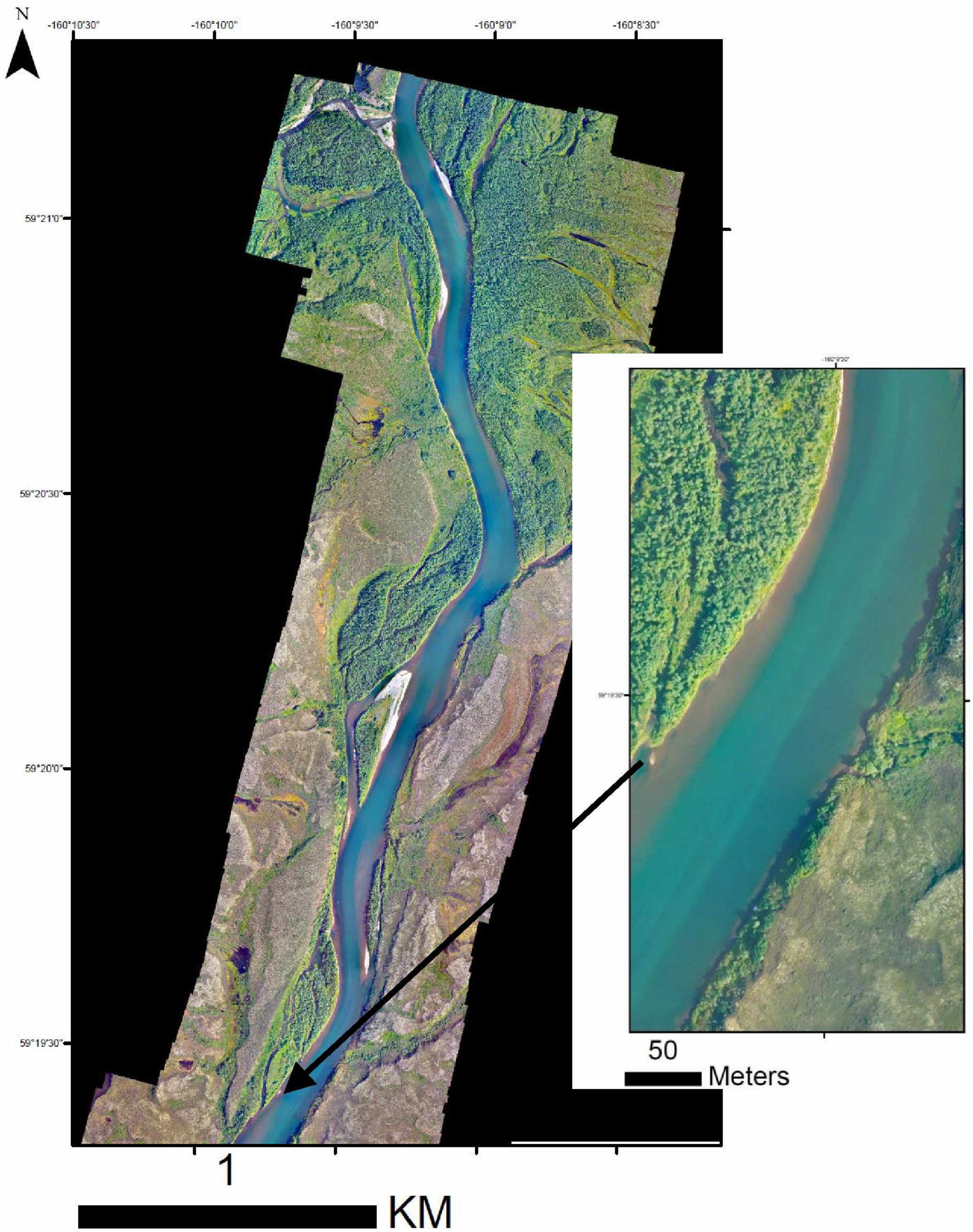


Figure1.4: Optical mosaic of the upstream section of the lower mainstem section in the Togiak River in southwest Alaska. Imagery collected in August 2012. Inset is zoomed in to show the detail and visibility of a small patch of gravel (~3 x 8 m).

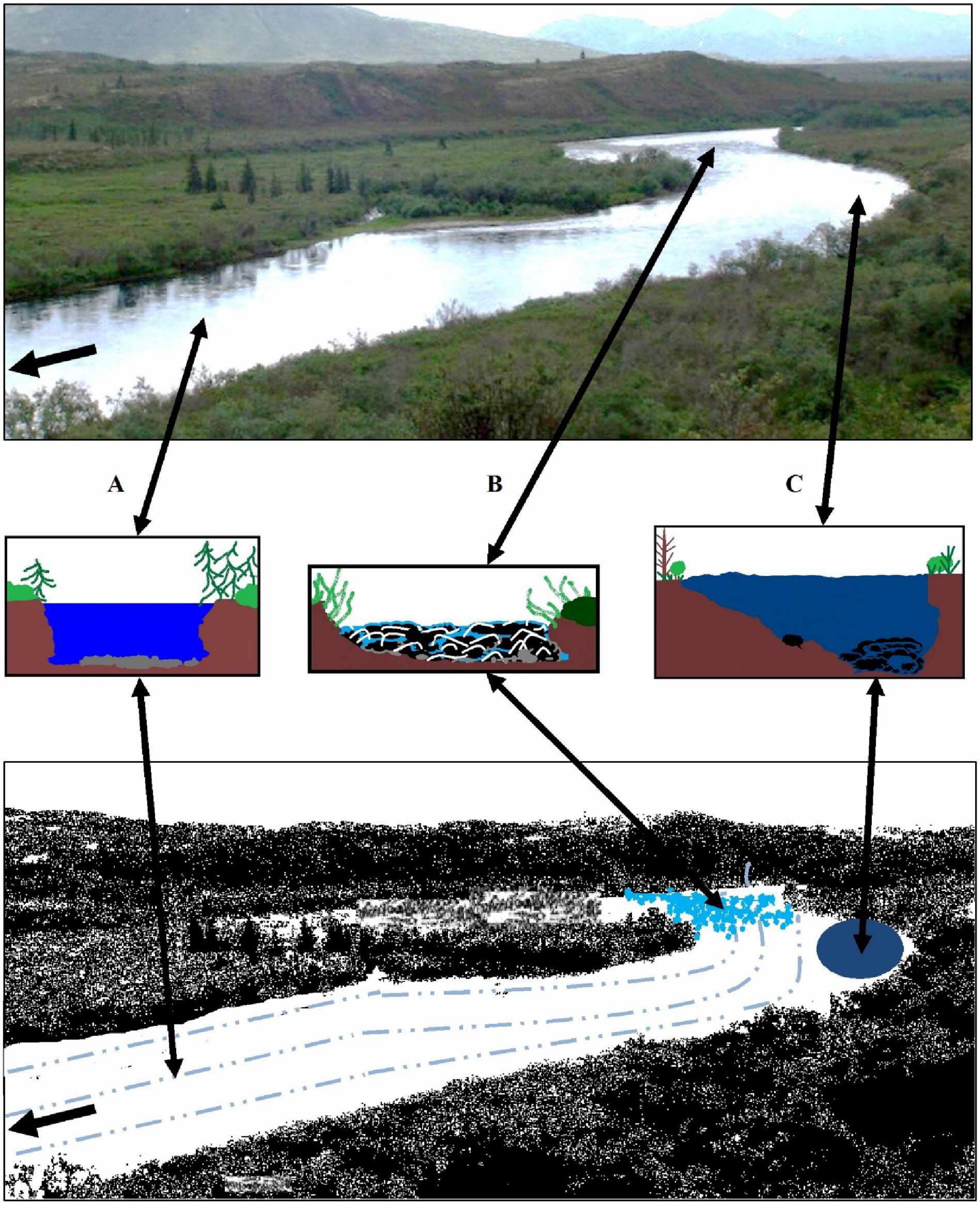


Figure 1.5: Photograph of a section of the Togiak River (top) and a graphical depiction (bottom) of channel features within a reach A) Run, B) Riffle, and C) Pool. Arrow on left-hand side of the photograph indicates direction of flow.

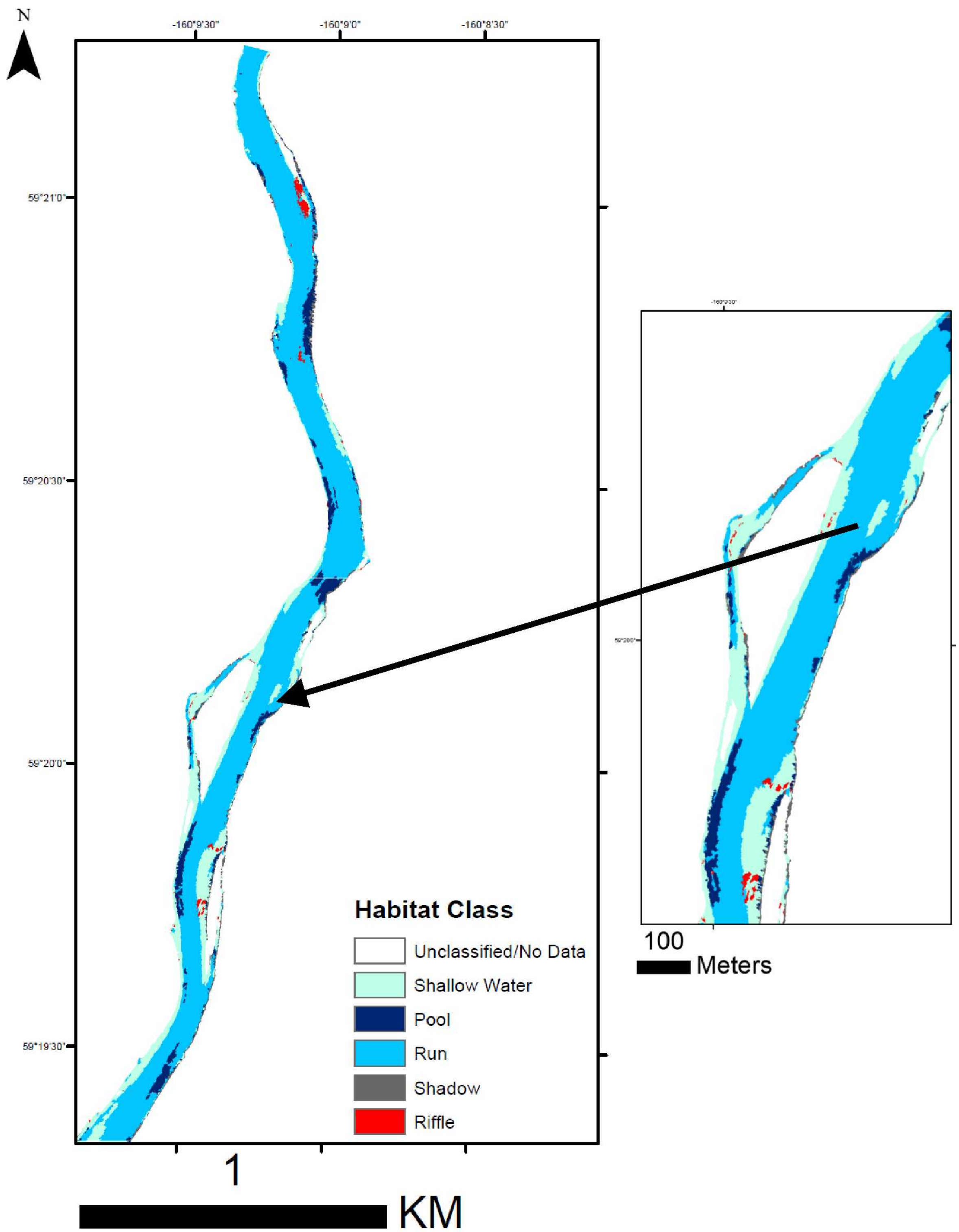


Figure 1.6: Object-based habitat classification of the upstream section of the lower mainstem section in the Togiak River in southwest Alaska. The optical imagery on which this classification was conducted was collected in August 2012. Inset is zoomed in to show detail in a small section of the river. Each habitat class is color coded for the five habitat classes used in the study.

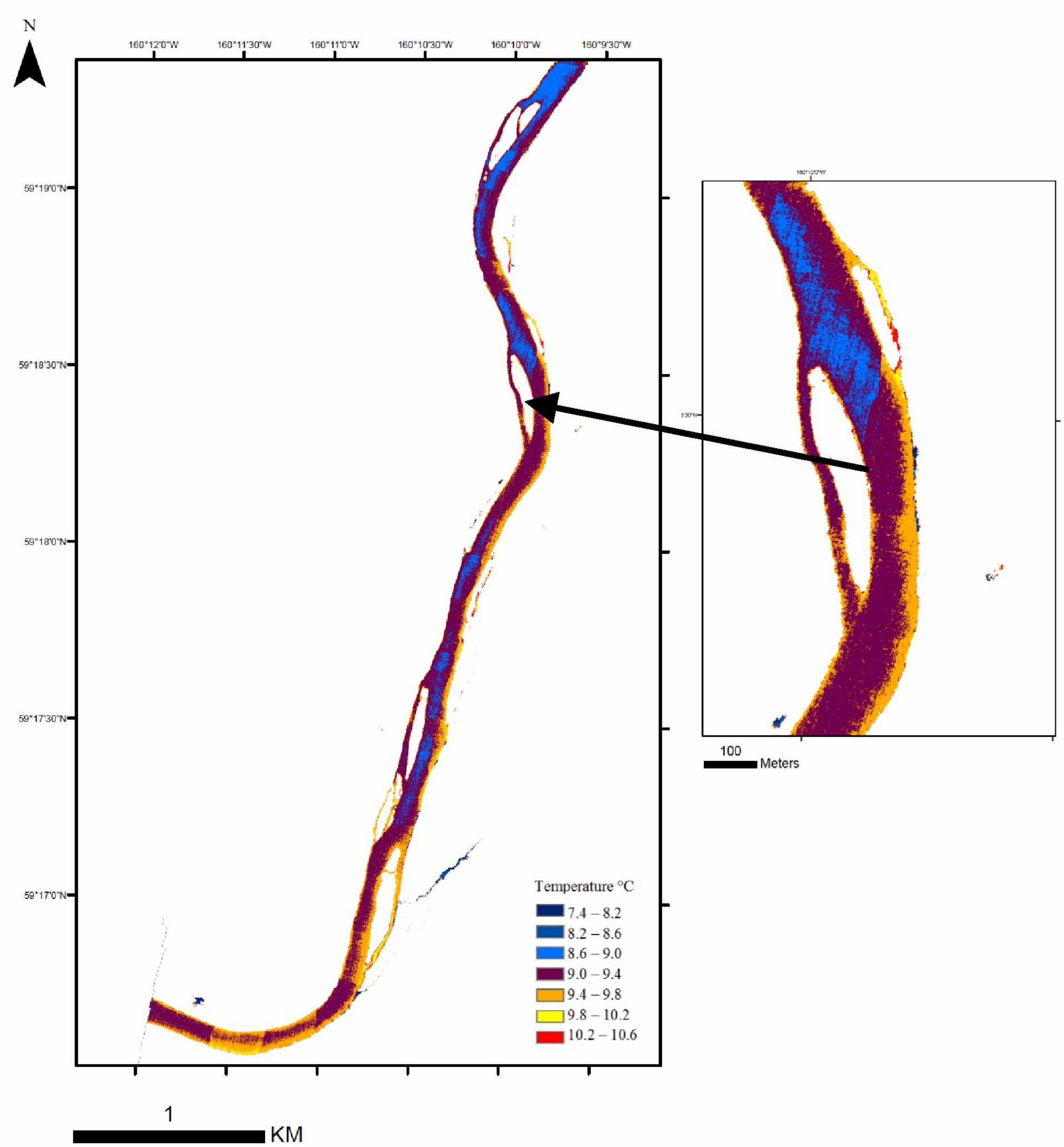


Figure 1.7: Thermal classification of the downstream section of the lower mainstem section in the Togiak River in southwest Alaska, based on Forward Looking Infrared (FLIR) imagery collected in August 2012. Inset is zoomed in to show detail in a small section of river. Each thermal bin is color coded with colder waters in the cooler colors (blue) and warmer water in the warmer colors (red).

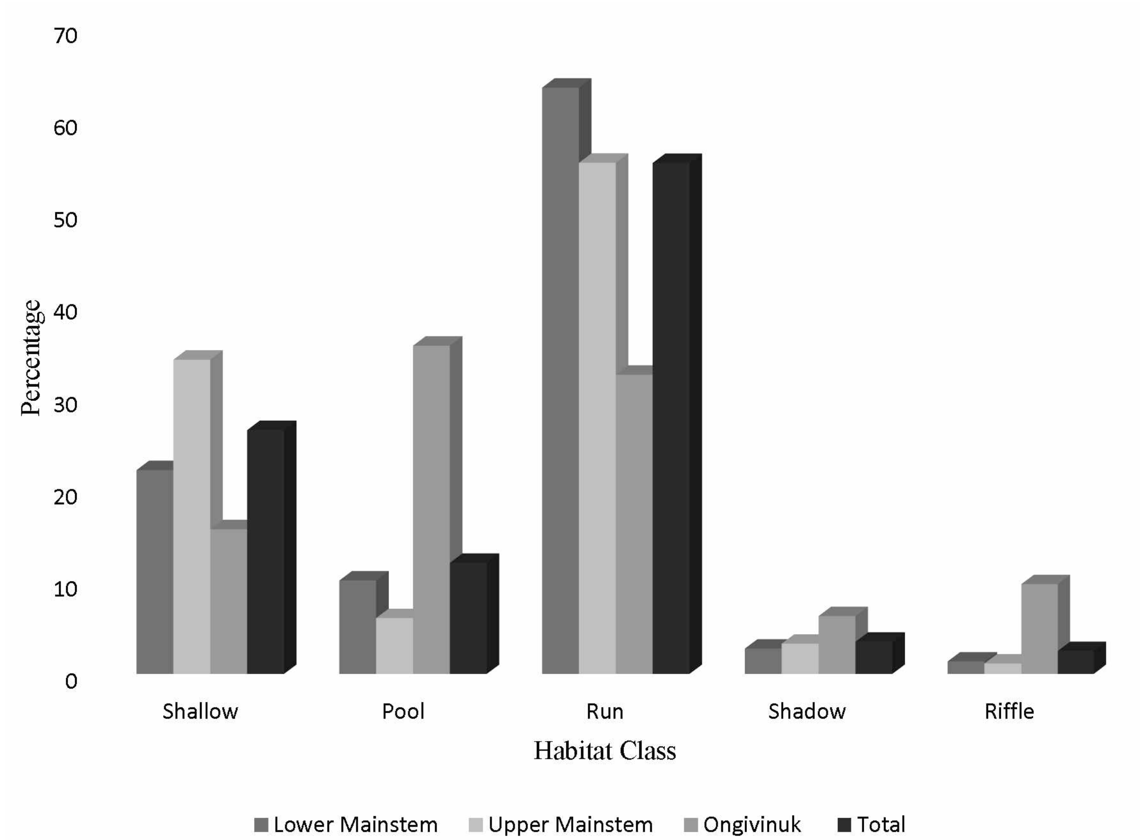


Figure 1.8: Percent occurrence of each habitat class derived from object-based classification of optical imagery in the entire study area and each reach.

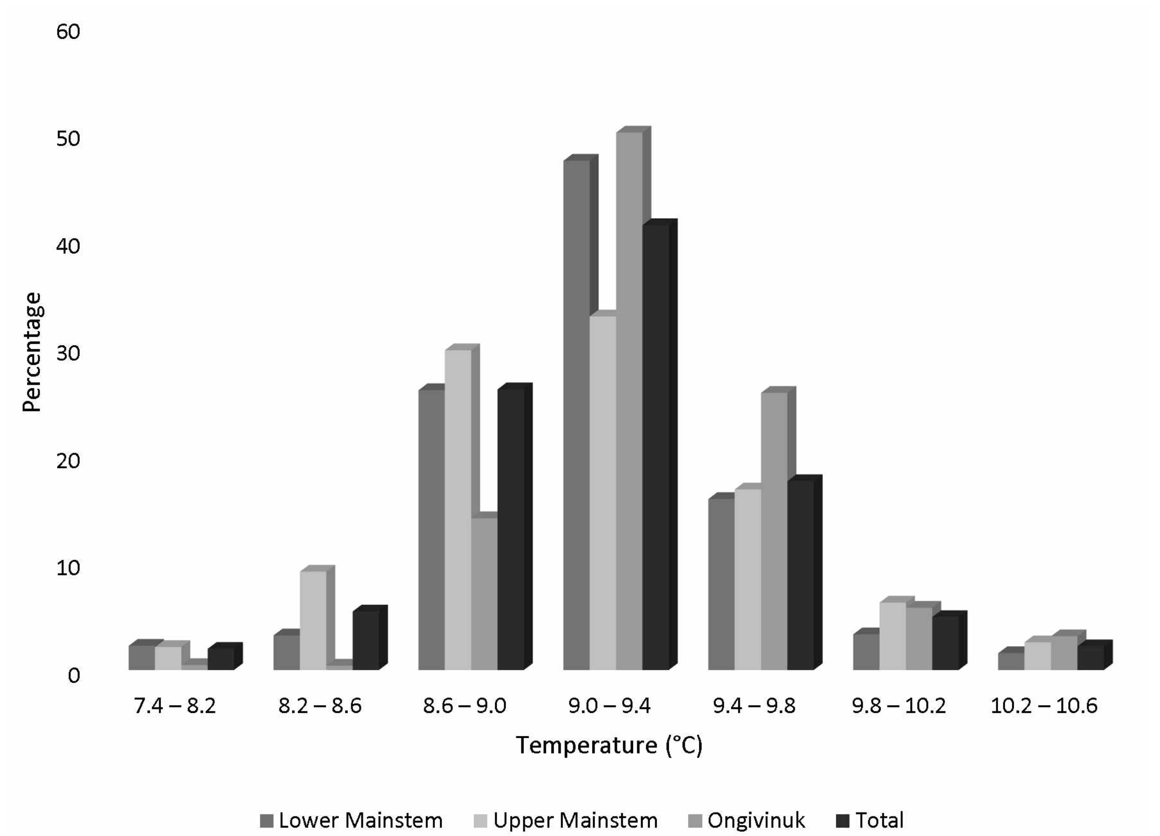
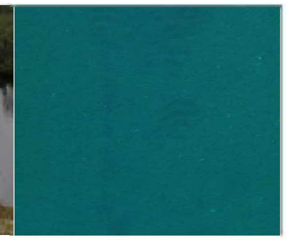
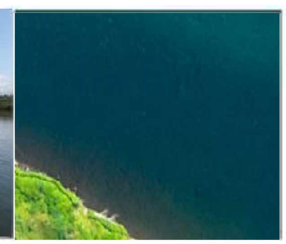
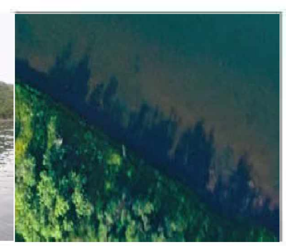
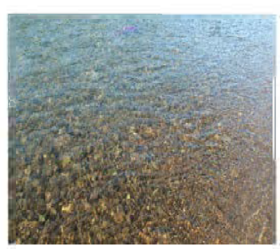


Figure 1.9: Percent occurrence of each thermal bin derived from thermal imagery in the entire study area and each reach.

Table 1.1: In-stream habitat classes included in this study for the Togiak River drainage in southwest Alaska, and comparisons between field photos and aerial photos.

Habitat Class	Field Description	Fluvial Processes	Field Photo	Aerial Photo
Run	Consistent channel shape; well-defined thalweg, moderate to fast current with minimal surface turbulence	Deeper than riffle, variable substrate but mostly course substrate (gravel, cobble, boulders); generally connect riffle and pool areas		
Riffle	Variable channel shape; shallow; fast moving water with substantial surface turbulence	Shallowest class with steepest slopes of incline or decline; course substrate; typically occur in cross-over locations		
Pool	Deep, slow to fast moving water, generally bowl shaped, minimal surface turbulence	Deepest class; in slow velocity substrate may contain sand and silt; in faster velocity, larger substrate; typically occur on outside of meander bends		
Shadow	Dark tones found along edges, generally follow the outline of vegetation found along river banks	None		
Shallow Water	Water depths generally $\leq$ 1 meter, with reddish brown tones	None		

Note: Field descriptions and fluvial processes modified from Woll et al. 2011 and West Virginia Department of Environmental Protection 2012.

Table 1.2: Confusion matrix produced by standard accuracy assessment techniques (Congalton and Green 1999) for the classification results for the entire study area in the Togiak River drainage in southwest Alaska.

		Ground Truth					
		Shallow Water	Pool	Run	Shadow	Riffle	Ground Total
Classifier	Shallow Water	257	1	13	0	29	300
	Pool	3	105	38	6	41	193
	Run	17	1	221	1	60	300
	Shadow	27	16	11	91	22	167
	Riffle	37	1	32	1	229	300
	Classification Total	341	124	315	99	381	1260

References

ADFG (Alaska Department of Fish and Game). 2018. Emergency orders and news releases. Kenai River king salmon limited to catch-and-release.

Agisoft PhotoScan. 2016. User manual professional edition. Retrieved from http://www.agisoft.com/pdf/photoscan-pro_1_2_en.pdf

Burkholder, B., G. Grant, R. Haggerty, T. Khangaonkar, and P. Wampler. 2008. Influence of hyporheic flow and geomorphology on temperature of a large, gravel-bed river, Clackamas River, Oregon, USA. Hydrological Processes 22(7): 941–953.

Carbonneau, P., and H. Piégay. 2012. Fluvial remote sensing for science and management. Chichester, West Sussex: Wiley-Blackwell.

Cardenas, M., J. Harvey, A. Packman, and D. Scott. 2008. Ground-based thermography of fluvial systems at low and high discharge reveals potential complex thermal heterogeneity driven by flow variation and bioroughness. Hydrological Processes 22(7): 980–986.

Congalton, R., and K. Green. 1999. Assessing the accuracy of remotely sensed data. Boca Raton, FL: Lewis Publishers.

Definiens Developer. XD 2.0.4 User Guide. 2012. Retrieved from https://www.imperial.ac.uk/media/.../Definiens-Developer-User-Guide-XD-2.0.4.pdf

Dugdale, S., N. Bergeron, and A. St-Hilaire. 2013. Temporal variability of thermal refuges and water temperature patterns in an Atlantic salmon river. Remote Sensing of Environment 136:358–373.

Dunckel, A., M. Cardenas, A. Sawyer, and P. Bennett. 2009. High-resolution in-situ thermal imaging of microbial mats at El Tatio Geyser, Chile shows coupling between community color and temperature. Geophysical Research Letters 36(23).

Dye, J., and C. Schawnke. 2012. Report to the Alaska Board of Fisheries for the recreational fisheries of Bristol Bay, 2010–2012. ADFG.

Elison, T., P. Salomone, T. Sands, G. Buck, K. Sechrist, and D. Koster. 2018. 2017 Bristol Bay management report. Fishery Management Report No. 18-11. ADFG.

Estensen, J.L., H.C. Carroll, S.D. Larson, C.M. Gleason, B.M. Borba, D.M. Jallen, S.K. Decker, A.J. Padilla, and K.M. Hilton. 2018. Annual management report Yukon Area, 2016. ADFG Fishery Management Report No. 18-14.

FLIR Systems. 2006. ThermaCAM EX320 user's manual. Retrieved from https://assets.tequipment.net/assets/1/26/Documents/EX320_manual.pdf

Foody, G. 2002. Status of land cover classification accuracy assessment. Remote Sensing of Environment 80(1):185–201.

Hamann, E., B. Kennedy, D. Whited, and J. Stanford. 2013. Spatial variability in spawning habitat selection by Chinook Salmon (*Oncorhynchus tshawytscha*) in a wilderness river. River Research and Applications 30(9):1099–1109.

Hawkins, C.P., J.L. Kershner, P.A. Bisson, M.D. Bryant, L.M. Decker, and S.V. Gregory, D.A. McCullough, C.K. Overton, G.H. Reeves, R.J. Steedman, M.K. Young. 1993. A hierarchical approach to classifying stream habitat features. Fisheries 18(6): 3–12.

Hay, G., and G. Castilla. 2006. Object-based image analysis: strengths, weaknesses, opportunities, and threats (SWOT). OBIA, 2006: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Retrieved from https://pdfs.semanticscholar.org/0c07/7b867fea1e4f1ff1dc2e9a9dc1b8b9d87932.pdf

Heard, W.R., E. Shevlyakov, O.V. Zikunova, R.E. McNicol. 2007. Chinook Salmon – Trends in abundance and biological characteristics. North Pacific Anadromous Fish Commission Bulletin No. 4:77–91.

Hetrick, N., K. Simms, M. Plumb, J. Larson. 2004. Feasibility of using video technology to estimate salmon escapement in the Ongivinuk River, a clear-water tributary of the Togiak River. USFWS.

Martinez, A., and M. Sims. 2012. River restoration - Physical habitat. Retrieved from https://riverrestoration.wikispaces.com/Physical+habitat

Mertes, L. 2002. Remote sensing of riverine landscapes. Freshwater Biology 47(4):799–816.

Monk, W., N. Wilbur, R. Allen Curry, R. Gagnon, and R. Faux. 2013. Linking landscape variables to cold water refugia in rivers. Journal of Environmental Management 118:170–176.

Ridgeway, J. 2006. Object-oriented approaches to mapping channel habitat on the lower Congo River. Master's Thesis. The University of Georgia.

Sands, T. 2012. Overview of the Bristol Bay salmon fishery 2010-2012, a report to the Alaska Board of Fisheries. ADFG.

Smikrud, K., A. Prakash, and J. Nichols. 2008. Decision-based fusion for improved fluvial landscape classification using digital aerial photographs and forward-looking infrared images. Photogrammetric Engineering and Remote Sensing, 74(7): 903–911.

Swaim, M. 2013. Stream temperature monitoring on Togiak National Wildlife Refuge, Alaska 2001–2012. Dillingham, Alaska: USFWS.

Tanner, T., and S. Sethi. 2014. Estimation of Chinook Salmon escapement, distribution and run timing in the Togiak River watershed using radiotelemetry, Togiak National Wildlife Refuge, Alaska, 2012. Anchorage, Alaska: USFWS.

Torgersen, C., R. Gresswell, and D. Bateman. 2004. Pattern detection in stream networks: quantifying spatial variability in fish distribution. In Second International Symposium on GIS/Spatial Analyses in Fishery and Aquatic Sciences:405–420.

Torgersen, C., D. Price, H. Li, and B. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of Chinook Salmon in Northeastern Oregon. Ecological Applications 9(1):301.

Torgersen, C., N. Poage, M. Flood, D. Norton, and B. McIntosh. 1996. Airborne thermal remote sensing of salmonid habitat for restoration planning in Pacific Northwestern watersheds. In Watershed 96 Conference. Alexandria, Virginia: Water Environment Federation.

USFWS (U.S. Fish and Wildlife Service). 2009. Comprehensive conservation plan Togiak National Wildlife Refuge. Anchorage, Alaska.

Weih, R., and N. Riggan, Jr. 2010. Object-based classification vs. pixel-based classification: Comparative importance of multi-resolution imagery. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Retrieved from http://www.isprs.org/proceedings/xxxviii/4-c7/pdf/Weih_81.pdf

West Virginia Department of Environmental Protection. 2012. West Virginia save our streams program level-one standard operating procedures manual. Charleston, West Virginia: West Virginia Department of Environmental Protection.

Woll, C., A. Prakash, and T. Sutton. 2011. A case-study of in-stream juvenile salmon habitat classification using decision-based fusion of multispectral images. Journal of Applied Remote Sensing, (2):37–46.

Wirth, L., A. Rosenberger, A. Prakash, R. Gens, J. Margraf, T. Hamazaki. 2012. A remote sensing/GIS-based approach to identify, monitor and model spawning habitat for fall chum salmon in a sub-arctic, glacially-fed river. Transactions of the American Fisheries Society 141(5):1349–1363.

Chapter 2: Habitat and Thermal Preferences of Spawning Chinook Salmon in the Togiak River, Alaska

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Abstract

Salmonids are heavily dependent on specific habitat characteristics for survival, yet few studies in Alaska have examined the relationship between habitat and spawning distribution using remote sensing approaches. To better understand the relationship between Chinook Salmon *Oncorhynchus tshawytscha* spawning distribution and environmental variables like habitat type (e.g., run, riffle, pool), temperature, and proximity to channel islands, optical and thermal imagery were collected on the Togiak and Ongivinuk rivers in southwest Alaska. Object-based image analysis was used to classify and quantify habitat types, while thermal characteristics and the proximity of spawning locations to channel islands were determined in a GIS framework. Chinook Salmon showed a preference for spawning in river runs, and 80% of fish spawned in water temperatures between 8.6° and 9.4°C and nearly 61% of Chinook Salmon spawned within 100 m of a channel island. This study provided a baseline understanding of environmental correlates of spawning for Chinook Salmon at the northern extent of their range.

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Introduction

River habitats are typically complex and can affect the abundance and distribution of fishes. Habitat types and temperature are frequently examined to understand fish distribution and abundance (Swales 2006). Chinook Salmon *Oncorhynchus tshawytscha* is an iconic fish species in North America, and almost all populations have experienced a decline in abundance. However, this species remains a highly prized fish in sport, commercial, and subsistence fisheries because of its large size and high-quality meat. Reasons for the decline in population may be from increased harvest rates, hatchery influences (e.g. disease, parasites, etc.), changing ocean conditions, marine mammal predation (Chasco et al. 2017), reduced genetic diversity (Johnson et al. 2018), and changes in habitat quality resulting from climate change (Crozier 2016).

Interactions between habitat and Chinook Salmon spawning behavior are particularly important to the survival of juvenile Chinook Salmon. For example, the interaction between water temperature and spawning of adult salmon impacts juvenile survival because the date at which they spawn and ambient water temperature are the primary mechanisms controlling offspring emergence (Gilhousen 1990; Quinn and Adams 1996; Quinn et al. 2000). Offspring that emerge earlier or later than the optimal time for a given population may have several disadvantages (Weber Scannell 1992). Spawn timing of specific populations is an adaptation to local thermal conditions and food availability; good spawn timing equates to increased rates of fry survival and vice versa.

Another example of an interaction between habitat and Chinook Salmon behavior is the type of habitats chosen for spawning. Because temperature and hydraulic processes occur non-uniformly throughout a river, Chinook Salmon spawning activity is patchy, and they tend to spawn in specific areas in rivers and ignore others that superficially appear similar (Vronskiy 1972). It is thought that the distribution of runs, riffles, pools, and channel complexity are factors related to salmonid spawning locations (Torgersen et al. 2004).

Chinook Salmon tend to spawn in pool-riffle habitats which frequently occur in areas with alluvial deposits (Groot and Margolis 1991; Torgersen et al. 1999; Hamann et al. 2013). Additionally, Chinook Salmon redd clusters tend to occur in areas with complex channel patterns, rather than in areas where the channel is straight and simple (Geist and Dauble 1998). Geomorphic features such as mid-channel islands increase channel complexity, and large gravel bars consisting of alluvial deposits associated with these islands are important for Chinook Salmon spawning. Chinook Salmon prefer to spawn in these areas because they typically have upwelling or downwelling that creates interstitial flow, also known as hyporheic flow, through bed material (Brunke and Gonser 1997; Visser 2000) on the upstream and downstream portions of a channel island. Intragravel flow has been shown to be critical and whether it is upwelling or downwelling may not be important (Geist and Dauble 1998), likely because hyporheic flows moderate temperatures and flow regimes (Brunke and Gonser 1997), and provide consistent oxygenation of eggs (Groot and Margolis 1991).

As a result of strict spawning habitat requirements and interannual consistency in habitat characteristics at microscales (<10s of m), Chinook Salmon spawning has been observed to occur in the same areas year after year (Klett et al. 2013), although the preferred habitat classes for spawning may vary depending on the river. For example, clusters of redds in the Hanford Reach (Columbia River in eastern Washington) tended to occur in areas with a complex channel pattern, rather than where the channel was straight and simple (Geist and Dauble 1998). In Big Creek (a tributary of the Middle Fork of the Salmon River in central Idaho), Chinook Salmon built redds in multiple habitat types, but transitional zones (included run/pool and run/riffle transitions) were chosen most frequently in upper Big Creek while pools and riffles were avoided. In lower Big Creek and middle Big Creek, riffles areas were chosen most frequently (Hamann et al. 2013).

In Alaska, Chinook Salmon is an important species in commercial, sport and subsistence fisheries. Chinook Salmon abundance has declined across multiple Alaskan stocks, resulting in closures or restrictions in commercial, sport, and subsistence fisheries. In the Yukon River drainage since 2007, restrictions have included reduced fishing periods, closures, and gear restrictions (Estensen et al. 2018) and in the Kenai River in 2018, restrictions limited sport fisherman to only catch-and-release of Chinook Salmon (ADFG 2018). In Bristol Bay in western Alaska, the Togiak River frequently supports the second largest harvest of Chinook Salmon, in sport (Dye and Schawnke 2012), commercial (Sands 2012; Elison et al. 2018), and subsistence fisheries (Elison et al. 2018). However, the Togiak River is experiencing declines in the number of adult Chinook Salmon being harvested, and it is assumed that this decline reflects decreasing abundance (Heard et al. 2007).

The reasons for the Chinook Salmon stock declines are currently unknown; however, local knowledge indicates that the riverine environment is changing (Pete Abraham, personal communication 2011). Specifically, tributaries are thought to be experiencing lower water levels and as a result, the spawning distribution of Chinook Salmon has shifted from tributaries to the mainstem. However, there is limited comprehensive scientific data about habitat characteristics of the Togiak River system to complement local knowledge.

Due to the challenges associated with measuring habitat characteristics in large, remote river locations, remote sensing image acquisition and image analysis is becoming more common in fisheries research (Mertes 2002). By utilizing remote sensing imagery, both large and small-scale habitat and temperature characteristics can be analyzed in conjunction with spawning distribution data from radio-tagged fish to understand the relationship between habitat characteristics and habitat occupation. Optical and forward-looking infrared (FLIR) imagery can be collected simultaneously via aircraft and can provide high-resolution and spatially continuous information about stream channel morphology and stream temperature (Torgersen et al. 2004; Chapter 1). This imagery can be used to understand salmonid habitat characteristics at the landscape level (Geist and Dauble 1998; Mertes 2002; Torgersen et al. 1999; Torgersen et al. 2004). Some previous remote sensing research has occurred towards the southern extent of the range of Chinook Salmon, yet few similar projects have occurred at the northern extent of this species' range.

The goal of this chapter was to understand environmental correlates of spawning distribution of Chinook Salmon in the Togiak and Ongivinuk rivers. The objectives were to (1) identify where Chinook Salmon spawn, (2) identify habitat type preferences for spawning, and (3) identify thermal preferences of spawning Chinook Salmon. Determining patterns and thermal preferences of Chinook Salmon spawning within the Togiak River is necessary to provide quantifiable baseline information against which future studies could be compared.

Methods

Study Site

This study was conducted within the Togiak River drainage in southwest Alaska which partially lies within the Togiak National Wildlife Refuge (TNWR; Figure 2.1). The Togiak River begins at the outlet of Togiak Lake and flows 93 rkm to Togiak Bay. It is surrounded by the Wood River Mountains to the east and the Ahklun Mountains to the west. The watershed is made up of nine major lakes, five major tributaries, and encompasses 5,178 km^2 (Tanner and Sethi 2014). Within the designated Wilderness Area, where the study occurred, a single main channel with occasional small islands, deep holes, and gravel point bars characterize the river. River substrate size ranges from sand to large cobble and medium size boulders (USFWS 2009). Two reaches, one each in the upper and lower portions of the mainstem Togiak River, were selected for analyses in this study, and are further referred to as lower mainstem and upper mainstem.

A portion of the Ongivinuk River, the uppermost tributary in the Togiak River watershed was also included for analyses in this study. The Ongivinuk River is a clear-water tributary (Hetrick et al. 2004) and is one of the most accessible tributaries during low water. The Ongivinuk River flows about 50 rkm from Ongivinuk Lake before emptying into the Togiak River, 70 km upstream from Togiak Bay (Hetrick et al. 2004). The river is characterized by a single main channel with numerous deep holes and gravel point bars along the inside bends (USFWS 2009).

Spawning Locations

To document Chinook Salmon spawning distribution, a radio telemetry mark-recapture project was conducted during 2008–2012 (Anderson 2009, 2010; Tanner and Sethi 2011, 2014). Extensive boat and aerial tracking of individual radio-tagged Chinook Salmon (n=573) was conducted annually throughout the watershed during the month of August, which allowed for repeated observations of individual fish that were clustered in both time and location. For this project, a final spawning location for each fish was determined when (1) an individual fish was detected in an area of approximately 100 m at least twice within a period of eight days, and (2) that period of eight days was between August 14 and August 31, which coincides with the known spawning time of Chinook Salmon in the Togiak River drainage (Tanner and Sethi 2014). If both requirements were met for that individual fish, a final spawning location was assigned (n=82).

Image Acquisition

On August 9, 2012, optical and thermal imagery were obtained in Nadir-looking aerial photos that were acquired using an USFWS-operated Bushhawk Found aircraft with camera ports in the aircraft floor. A Nikon D700 digital camera was used to collect optical images in the visible spectrum and a FLIR A320 automation series camera was used to collect thermal imagery. Approximately 36 rkm of mosaics were created, roughly 10 rkm in each of the lower mainstem and Ongivinuk River, and 16 rkm in the upper mainstem (Chapter 1).

Habitat Classification and Spawning Preference

Optical images were pre-processed with Adobe Lightroom 4 (© Adobe Systems) and Agisoft PhotoScan (version 0.9.0) and were classified using Trimble eCognition® Developer version 8.9.0 (©2014 Trimble Geospatial Imaging; Figures 2.2 to 2.4). Habitat was classified into three main classes (runs, riffles, and pools) and two secondary classes (shallow water and shadows; Chapter 1). In this study, an additional habitat class was created using the polygon tool in ArcMap 10.3.1, which was used to trace the outline of each channel island with established vegetation in the study area.

Spawning locations were overlaid on the habitat classification mosaic (Figures 2.2 to 2.4) to determine if spawning fish were selecting or avoiding habitat classes in proportion to availability. Jacob's electivity analysis (Jacobs 1974; Manly et al. 1993; Hamman et al. 2013) was calculated for each section in the study area (upper mainstem, lower mainstem, Ongivinuk

River) and for all three sections combined. Jacob's index was determined using the following formula:

$$D = (r - p)/(r + p - 2rp) \tag{2.1}$$

where 'r' is the proportion of habitat used, 'p' is the proportion of habitat available and 'D' varies from -1 to +1. Values near 0 indicate that a habitat was used in proportion to its availability in the environment (Hamann et al. 2013), while negative values suggest avoidance and positive values suggest preference.

Bonferroni normal statistics were used to calculate confidence intervals where:

$$\hat{p}_i - z_{\frac{\alpha}{2k}} \left[\frac{\hat{p}_i\,(1-\hat{p}_i)}{n}\right]^{\frac{1}{2}} \leq\ p_i\ \leq\ \hat{p}_i + z_{\frac{\alpha}{2k}} \left[\frac{\hat{p}_i\,(1-\hat{p}_i)}{n}\right]^{\frac{1}{2}} \tag{2.2}$$

and $\hat{p}_i$ is the proportion of locations in each habitat type *i*, and $z_{\frac{\alpha}{2k}}$ is the upper standard normal variate corresponding to a probability tail area of ${}^{\alpha}/_{2k}$. The $2k$ denominator under α is used because multiple confidence intervals are being computed simultaneously. Bonferroni normal statistics were used with *k* = 5 and $z_{\frac{1-\alpha}{2k}}$ = 2.576 and α = 0.05 (White and Garrott1990; Torgersen et al. 1999). If the confidence interval included the proportion of habitat available, then the preference or avoidance of Jacob's electivity index was not statistically significant.

Proximity Analysis

To determine proximity of spawning locations to channel islands, the near tool (ArcMap 10.3.1) was used to calculate the distance in meters between each fish's spawning location and the nearest channel island. A histogram was created to display the frequency of proximity between spawning sites and channel islands in a variety of distance bins. All spawning locations within 100 m were then visually examined and designated as upstream, downstream, or adjacent to the nearest channel island, and a percentage to determine where Chinook Salmon spawned was calculated.

Thermal Classification and Spawning Preference

FLIR imagery was orthorectified and geometrically corrected using ground control points, and was then mosaicked using EnsoMOSAIC (Chapter 1). ArcGIS ArcMap 10.3.1 was used to classify the thermal imagery into temperature bins ranging from 7.4° to 10.6°C (Figure 2.2 to 2.4). The first bin was 7.4°–8.2°C; the remaining bins were in 0.4°C increments, which is twice the temperature sensitivity of the thermal camera (0.2°C). The weighted average temperature was calculated for the upper mainstem, lower mainstem, and Ongivinuk River sections using:

$$\frac{\sum(Temperature * Pixel\ Count)}{Total\ Pixel\ Count} \qquad 2.3$$

To determine if spawning fish were selecting or avoiding certain thermal temperatures, in proportion to availability, Jacob's electivity analysis was calculated using thermal bins for each river reach in the study area (i.e. upper mainstem, lower mainstem, Ongivinuk River) and for all three sections combined.

Bonferroni normal statistics were used to calculate confidence intervals where:

$$\hat{p}_i - z_{\frac{\alpha}{2k}}\left[\frac{\hat{p}_i\,(1-\hat{p}_i)}{n}\right]^{\frac{1}{2}} \leq\ p_i\ \leq\ \hat{p}_i + z_{\frac{\alpha}{2k}}\left[\frac{\hat{p}_i\,(1-\hat{p}_i)}{n}\right]^{\frac{1}{2}} \qquad 2.4$$

and $\hat{p}_i$ is the proportion of locations in each habitat type *i*, and $z_{\frac{\alpha}{2k}}$ is the upper standard normal variate corresponding to a probability tail area of $^{\alpha}/_{2k}$. The $2k$ denominator under α is used because multiple confidence intervals are being computed simultaneously. Bonferroni normal statistics were used with $k = 7$ and $z_{\frac{1-\alpha}{2k}} = 2.692$ and $\alpha = 0.05$ (White and Garrott 1990; Torgersen et al. 1999). If the confidence interval included the proportion of habitat available, then the preference or avoidance of Jacob's electivity index is not statistically significant.

Results

Spawning Locations

Due to the rigorous requirements to confidently assign a spawning location, only 82 of the 573 (~14.3%) radio-tagged Chinook Salmon were included the analyses in this project. Forty-three Chinook Salmon were assigned spawning locations in the lower mainstem, 33 in the upper mainstem, and 6 in the Ongivinuk River.

Habitat Classification and Spawning Preference

When the three river reaches were combined, 76% of Chinook Salmon choose run habitat for spawning, followed by pools (13%), shallow water (9%), and riffles (2%). The electivity analysis suggested that fish showed a strong preference for runs (0.915), avoided shallow water (-0.588) and shadows (-1.0), and riffles and pools were used in proportion to availability when the entire study area was considered (Table 2.1). In the lower mainstem, only shallow water and shadow habitat classes indicated avoidance was statistically significant; all other habitat classes were used in proportion to availability. In the upper mainstem, runs were preferred, and all other habitat classes were avoided. In the Ongivinuk River, the number of fish (n=6) were not sufficient to determine statistical significance as a river reach, but fish were included in the combined electivity analysis.

Proximity Analysis

A total of 40 channel islands were digitized, including 21 channel islands in the lower mainstem, 11 islands in the upper mainstem, and 8 islands in the Ongivinuk River. Nearly 61%

of Chinook Salmon (50 of 82 fish) spawned within 100 m of a channel island. The first quartile for all fish was 39.2 m, the second quartile (and median) was 76.6 m, and the third quartile was 290.9 m. Of those 50 spawning locations that occurred within 100 m of a channel island, 78% spawned adjacent to a channel island, 6% spawned upstream of a channel island, and 16% spawned downstream of a channel island.

Thermal Classification and Spawning Preference

The mainstem (9.2°C) and the Ongivinuk River (9.3°C) had similar weighted mean temperatures. No fish spawned in temperatures colder than 8.2°C or warmer than 10.2°C, while 96% of fish spawned in water of 8.6–9.8°C, with 35% in 8.6–9.0°C, 45% in 9.0–9.4°C, and 16% in 9.4–9.8°C (Table 2.4). In the lower mainstem and Ongivinuk River reaches, spawning locations occurred in slightly warmer water of 9.0–9.4°C (48.8% and 5/6 fish respectively) than those in the upper mainstem, where 51.5% of fish spawned in 8.6–9.0°C water. Based on Jacob's electivity analysis (Table 2.2), Chinook Salmon avoided temperatures <8.2°C and >10.2°C in all three river reaches and when combined for the total study area. In the total study area, that was the only statistically significant result, as all other temperature bins were used in proportion to availability. Preference was shown in the upper mainstem for Chinook Salmon spawning in water temperatures between 8.6–9.0°C and in the Ongivinuk River in water temperature between 9.0–9.4°C.

Discussion

The majority of Chinook Salmon in the Togiak River system spawned in runs and showed a strong preference for this habitat type, which was the dominant type in the study area. Our findings contrast with those from the lower Big Creek in Idaho, where runs were avoided or used in proportion to availability in upper Big Creek (Hamann et al. 2013). The preference for spawning primarily in runs is likely because this habitat type has relatively deep water and more suitable medium-sized cobble than other types (personal observation). Similar habitat preferences have been well documented near Ive Island and Pierce Island of the Columbia River where deep water (> 1 m) spawning has occurred in up to 7.6 m water with predominately (over 90%) medium-sized cobble (7.6 cm to 15.2 cm) as the dominant substrate class at the redd site (Mueller 2005). As a corollary, the avoidance of shallow water and shadows was not unexpected because shallow water and shadows were close to the shoreline, which Chinook Salmon may avoid because of terrestrial predators. Specifically, adjacent to the Togiak River, there are large populations of brown and black bears that may influence spawning salmonids to avoid shallow water areas (Quinn et al. 2001).

Similar to previous research conducted in the Hanford Reach of the Columbia River (Geist and Dauble 1998; Visser 2000), Chinook Salmon in the Togiak River system often spawned near channel islands. Spawning near channel islands is hypothesized to take advantage of hyporheic flow typically associated with these features, which is thought to provide high rates of oxygenation to eggs and metabolic waste removal (Quinn 2005), as well as to moderate flow and temperature (Brunke and Gonser 1997). Incidentally, there also were spawning locations near vegetated gravel bars that become islands in higher flow regimes. These vegetated gravel bars that were connected to land likely share similar hyporheic flow characteristics as mid-channel islands.

Chinook Salmon avoided relatively warm and cold temperatures, with all fish spawning in water between 8.2–10.2°C. These temperatures are within the range of preferred temperatures for both upstream migration (9.4°–14.2°C; Bell 1986) and spawning (5.6°–10.6°C; Bell 1986) as documented in the Pacific northwest. Preferred migration and spawning temperatures across the range of Chinook Salmon may indicate a trait that is conserved across multiple spatially distant populations.

Interestingly, the temperature of the Ongivinuk River was similar to both mainstem sections, despite the general assumption that tributaries are colder than river mainstems. The similar temperatures between the Ongivinuk and the mainstem are of particular note because Togiak River Chinook Salmon show a difference in run-timing between tributary and mainstem spawning fish (Sethi and Tanner 2014), with tributary spawning fish entering earlier. Because of this earlier entrance and the preference for selecting slightly warmer temperatures, the accumulated temperature units for tributary ova may be changing and could result in premature emergence and/or poor fry survival and may provide some insight to corroborate local TEK as to why the spawning distribution has shifted towards more mainstem spawning fish.

Although our study provides a valuable starting point for understanding the relationship between spawning distribution of Chinook Salmon in the Togiak River watershed and habitat characteristics, two important caveats should be noted. First, although our study provided a good starting point for longitudinal stream temperature data, these data are merely a temporally and spatially limited snapshot of temperatures to which Chinook Salmon in the Togiak River may be exposed. Longer-term data sets from the Togiak National Wildlife Refuge (2002–2012; Swaim 2013), documented a broader range of temperatures (mid-column water temperature recording), but with limited spatial coverage. In the lower Togiak River, between mid-July and late-August, daily mean temperatures ranged from 12.0–16.2°C with a peak hourly recording of 17.8°C recorded in August 2004. There were no temperature loggers in the Ongivinuk River, but two other tributaries (Gechiak River and Pungokepuk Creek) had temperature loggers from 2002–

2012. Pungokepuk Creek experienced similar temperatures to the mainstem between mid-July and late-August, when daily mean temperatures ranged from 12.0–16.5°C with a peak hourly recording of 19.3°C recorded in July 2004. Warmer stream temperatures were recorded in Gechiak River between mid-July and late-August, when daily mean temperatures ranged from 17.4–22.3°C, with a peak hourly recording of 23.4°C recorded in July 2004 (Swaim 2013). Additionally, winter temperature trends within the Togiak watershed are quite variable among different tributaries and years (Swaim 2013). This variability in both summer and winter temperatures among the mainstem and several tributaries may cloud the relationship between water temperatures and shifts in spawning distribution.

Second, caution should be taken when interpreting results from the Ongivinuk River because of the small sample size of assigned spawning locations, all of which were derived from aerial tracking. A likely artifact of the small sample size is that only Chinook Salmon in the Ongivinuk River showed a strong thermal preference and avoidance for any specific temperature ranges, as opposed to being a true biological phenomenon. This bias introduced from the small sample size may have been further exacerbated by spawning locations determined by aerial tracking, which are less accurate than locations derived from boat tracking. Although the assigned spawning locations met the strict requirements, these locations often fell outside the boundaries of the river and were therefore snapped to the closest intersection with water, thus causing some inherent inaccuracy of spawning locations in this tributary. Finally, a limitation of using preference and avoidance as an indicator of significance, is that when a habitat class is not used by a spawning fish, it is significantly avoided, regardless of its abundance.

Conclusion

The study was able to determine that Chinook Salmon in the Togiak River preferred runs near mid-channel islands in intermediate temperatures for spawning. This combination of habitat characteristics likely provides an optimal set of conditions for juvenile survival, thus increasing the fitness of individual Chinook Salmon that spawn in these locations. There is broad agreement within the river sciences that water temperatures within northern habitat and temperate watersheds will increase under future climate change scenarios (Dugdale et al. 2013). In Alaska, elevations in temperature may be particularly harmful to fish adapted to cold water conditions that rarely experience significant summer warming (Weber Scannell 1992). Unfortunately, southwest Alaska is one of the fastest warming regions and its aquatic resources are at risk from a changing climate and this study provided important information on the current conditions of habitat and water temperatures in the Togiak and Ongivinuk rivers. Additionally, object-based image analysis and longitudinal temperature profiles may be applicable to other Alaskan watersheds to provide additional information on Chinook Salmon at the northern end of their range.

Acknowledgements

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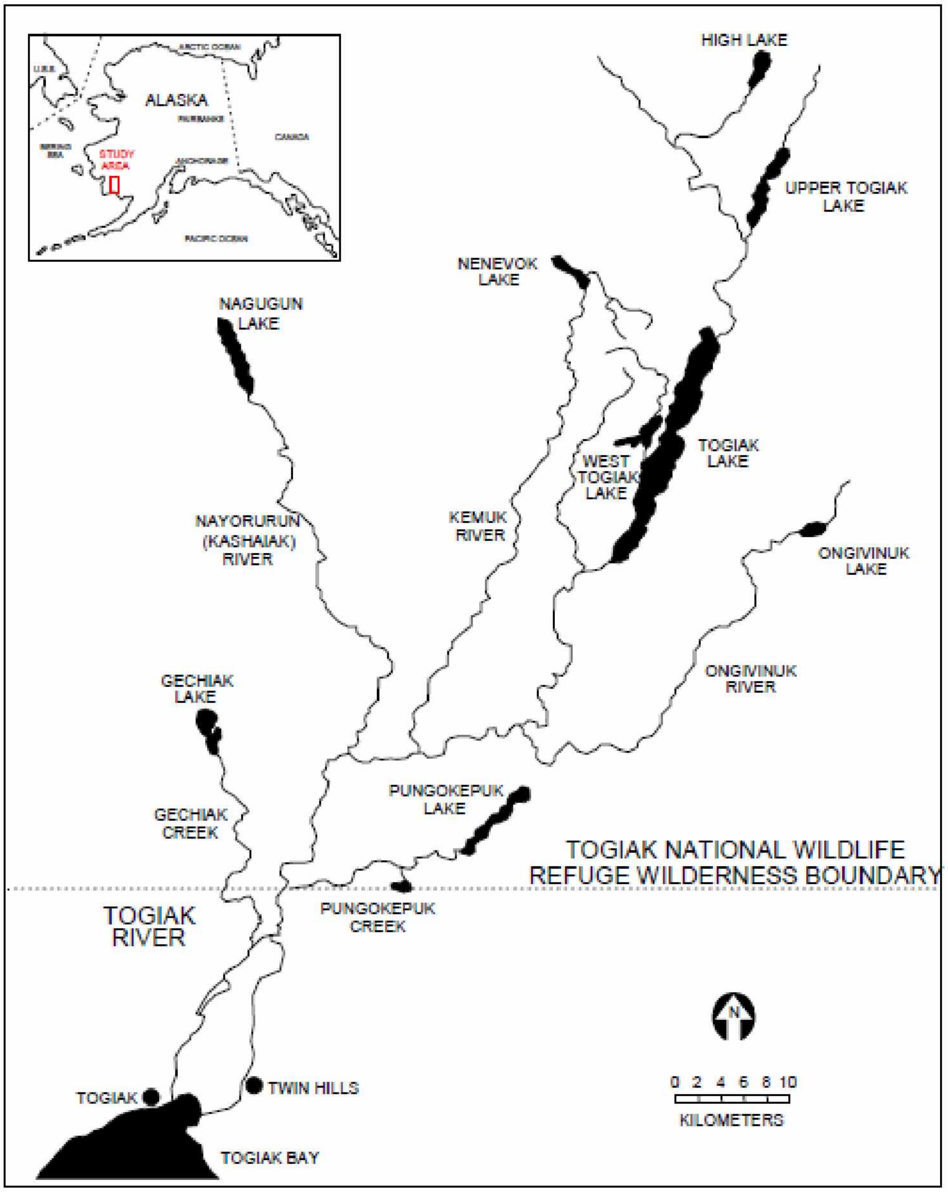

Figure 2.1: Map of Togiak River watershed in southwest Alaska, with prominent water bodies indicated (Tanner and Sethi 2014).

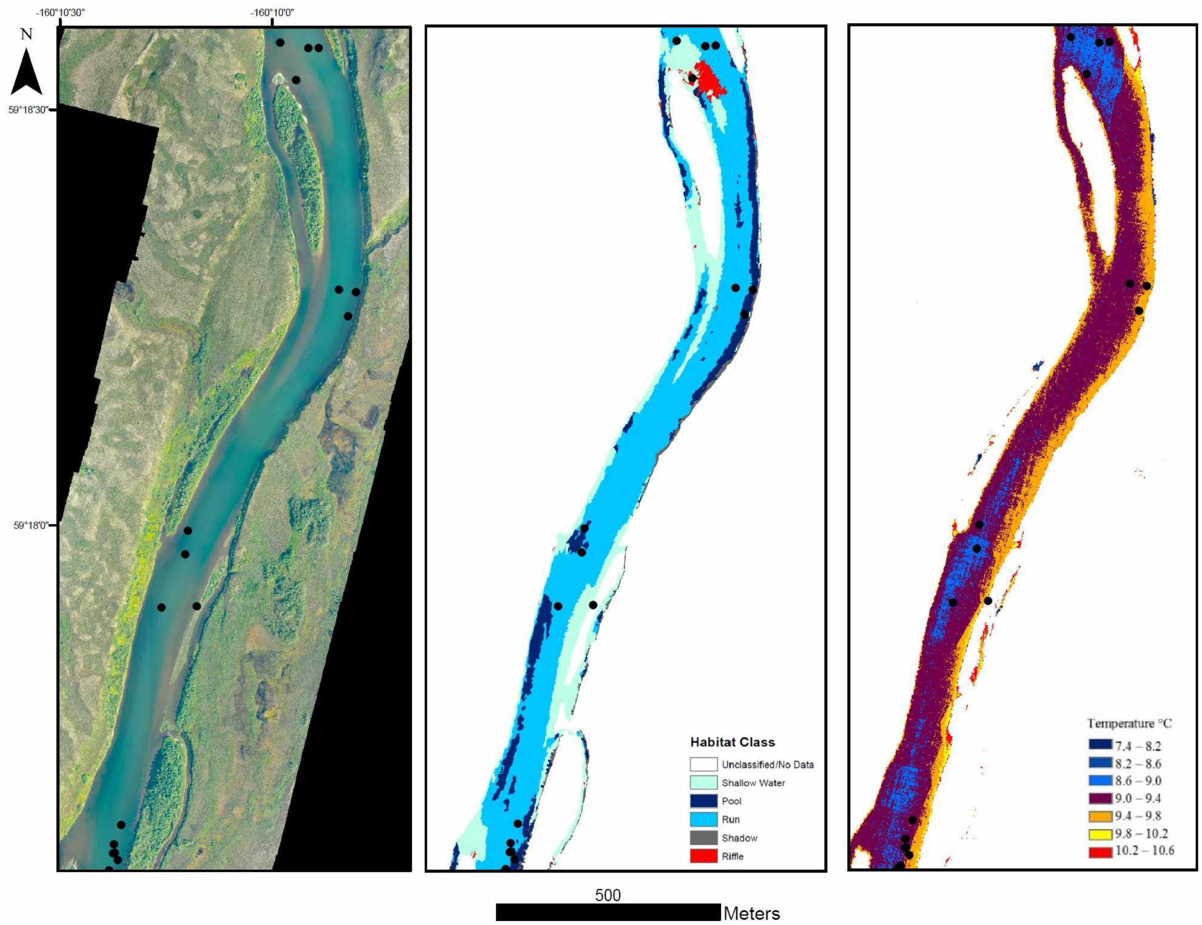

Figure 2.2: Optical image mosaic (left), object-based habitat classification (center), and thermal classification (right) of one section of the lower mainstem of the Togiak River in southwest Alaska collected in August 2012, with Chinook Salmon spawning locations overlaid (black circles).

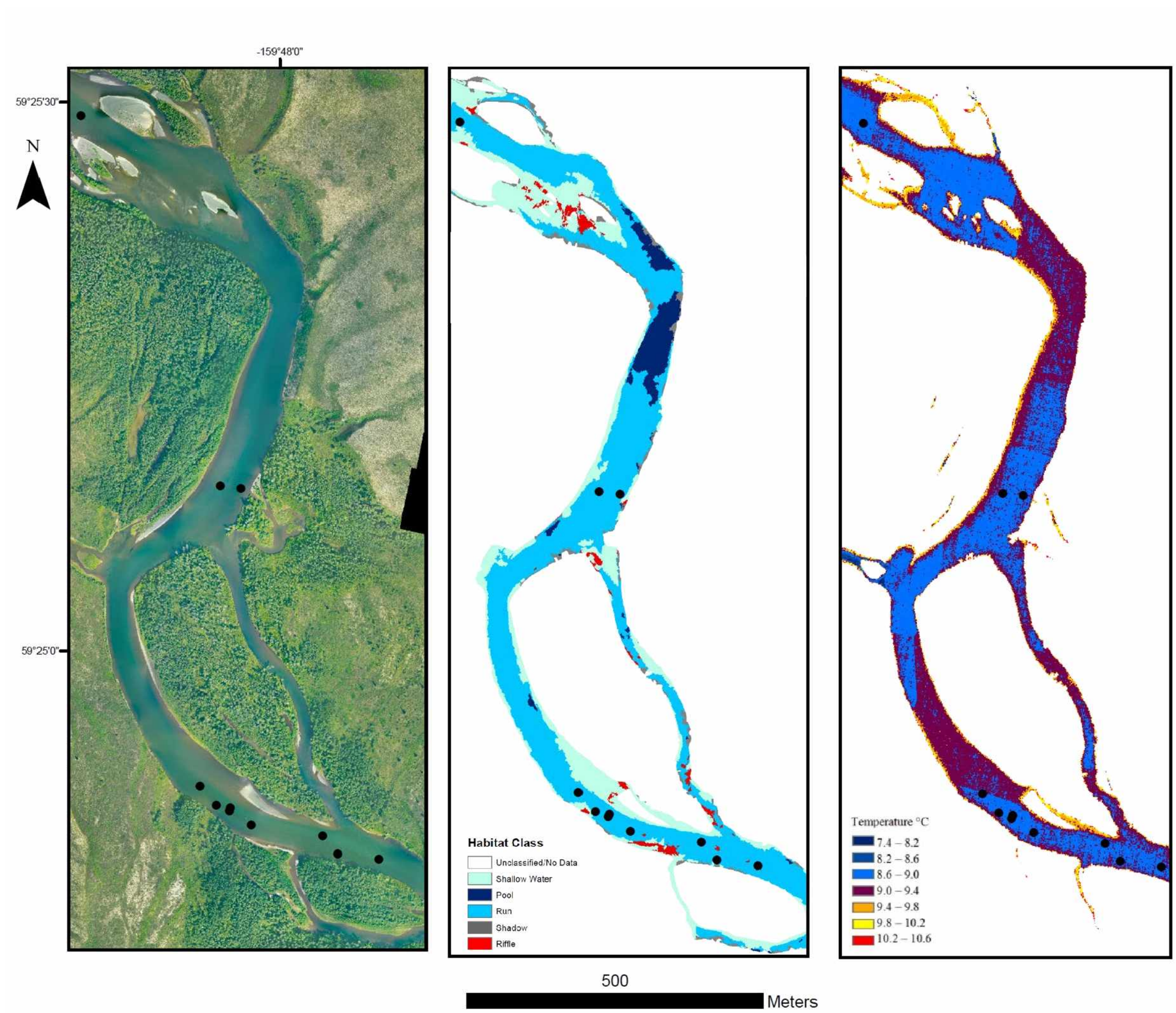

Figure 2.3: Optical image mosaic (left), object-based habitat classification (center), and thermal classification (right) of one section of the upper mainstem of the Togiak River in southwest Alaska collected in August 2012, with Chinook Salmon spawning locations overlaid (black circles).

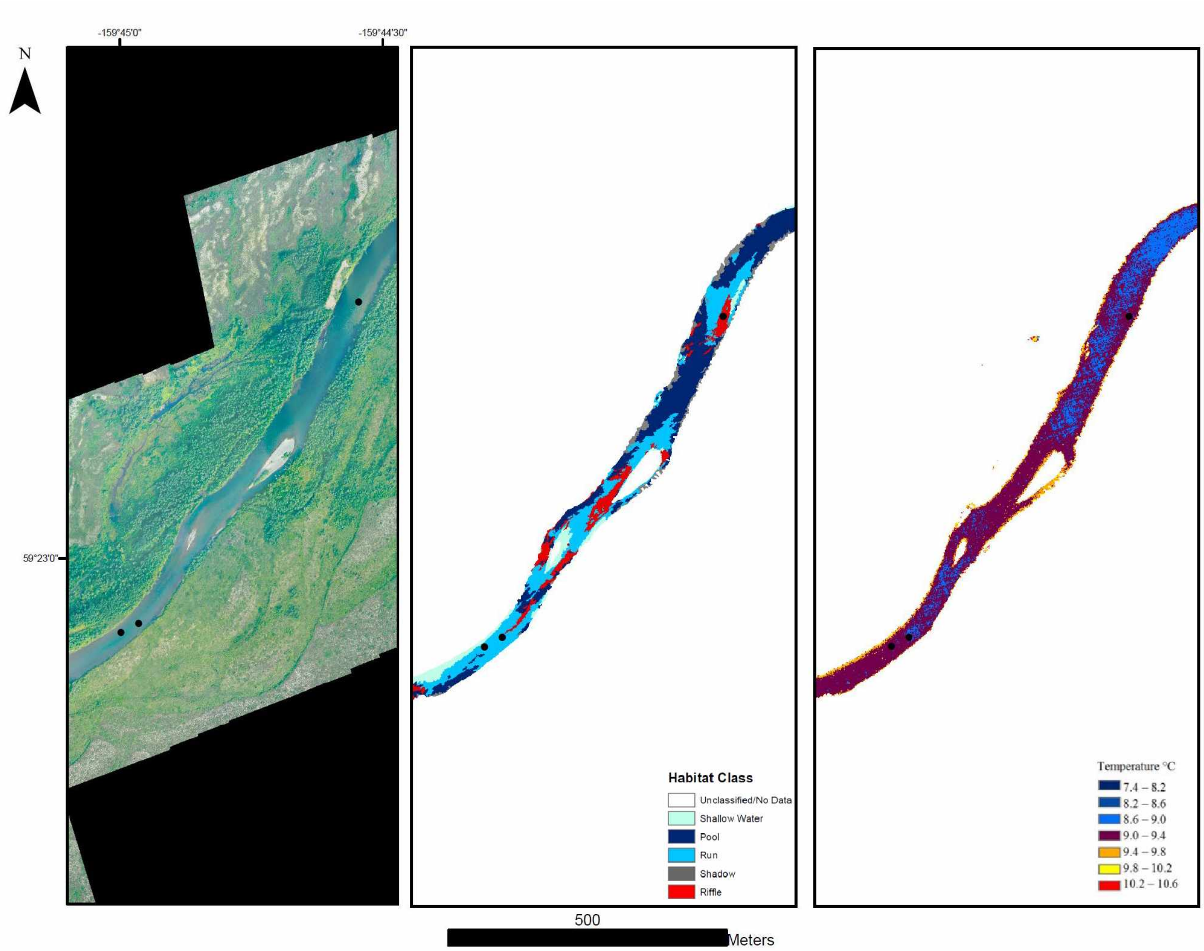

Figure 2.4: Optical image mosaic (left), object-based habitat classification (center), and thermal classification (right) of one section of the Ongivinuk River in southwest Alaska collected in August 2012, with Chinook Salmon spawning locations overlaid (black circles).

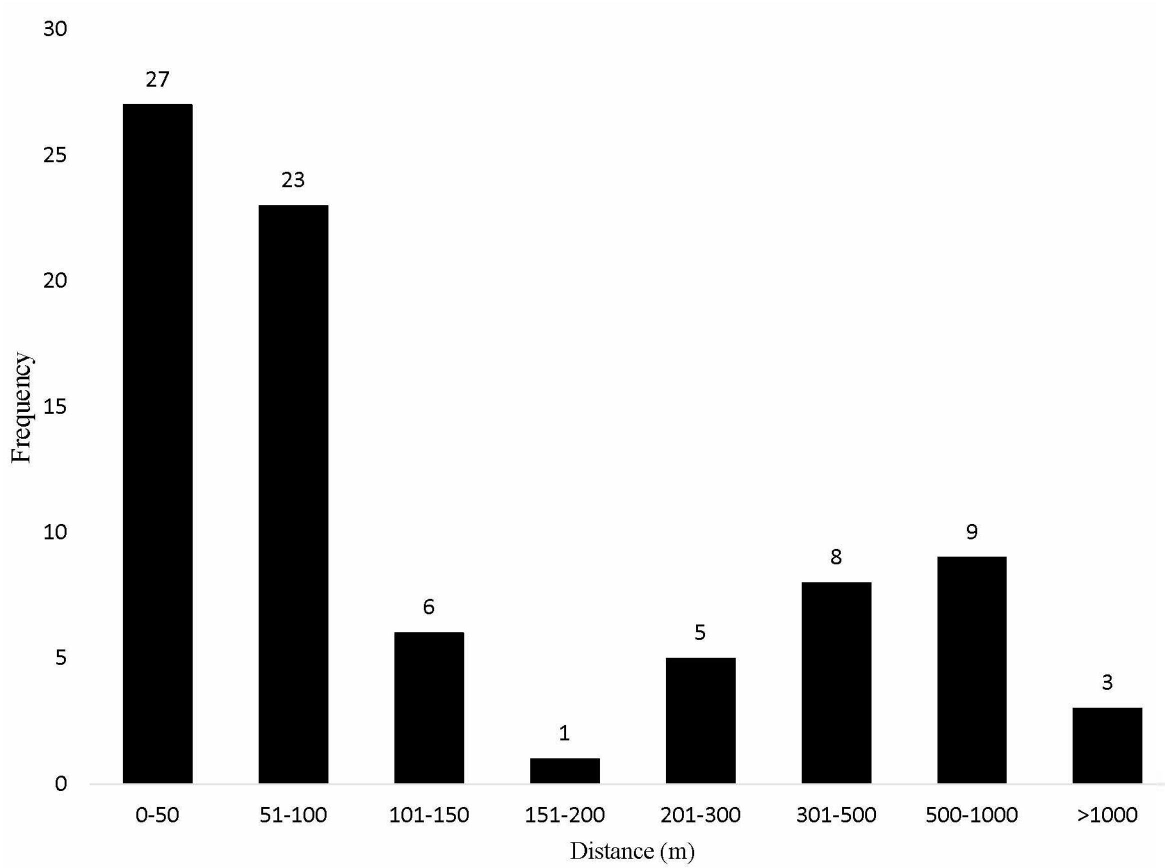

Figure 2.5: Histogram of distance between Chinook Salmon spawning locations and gravel islands in the Togiak River drainage in southwest Alaska, for all three study reaches combined.

Table 2.1: Jacob's electivity analysis examining the relationship between Chinook Salmon spawning locations and habitat classes in individual river reaches and all combined.

	Habitat Proportion	Spawning Fish Count	Used Sample Proportion	Lower 95%	Upper 95%	Jacob's Electivity Index
Lower Mainstem						
Shallow Water	0.221	3	0.070	-0.030	0.170	-0.582
Run	0.635	29	0.674	0.490	0.858	0.087*
Riffle	0.014	1	0.023	-0.036	0.082	0.253*
Pool	0.102	10	0.233	0.067	0.399	0.455*
Shadow	0.028	0	0.000	0.000	0.000	-1.000
Upper Mainstem						
Shallow Water	0.341	4	0.121	-0.007	0.249	-0.579
Run	0.553	29	0.879	0.751	1.007	0.708
Riffle	0.012	0	0.000	0.000	0.000	-1.000
Pool	0.061	0	0.000	0.000	0.000	-1.000
Shadow	0.033	0	0.000	0.000	0.000	-1.000
Total Study Area						
Shallow Water	0.265	7	0.085	-0.024	0.195	-0.588
Run	0.553	62	0.756	0.587	0.925	0.915
Riffle	0.025	2	0.024	-0.036	0.085	-0.960*
Pool	0.121	11	0.134	0.000	0.268	0.617*
Shadow	0.035	0	0.000	0.000	0.000	-1.000
Total		82				

Positive values indicate a preference for that habitat based on proportion to availability, 0 indicates use in proportion to availability (neutral), and negative values indicates avoidance of that habitat ($\alpha = 0.05$). *Indicates that the result was not statistically significant.

Table 2.2: Jacob's electivity analysis examining the relationship between Chinook Salmon spawning locations and temperature classes in individual river reaches and all combined.

	Habitat Proportion	Spawning Fish Count	Used Sample Proportion	Lower 95%	Upper 95%	Jacob's Electivity Index
Lower Mainstem						
7.4–8.2	0.023	0	0.000	0.000	0.000	-1.00
8.2–8.6	0.033	0	0.000	0.000	0.000	-1.00
8.6–9.0	0.261	11	0.256	0.077	0.435	-0.01*
9.0–9.4	0.474	21	0.488	0.283	0.694	0.03*
9.4–9.8	0.160	10	0.233	0.059	0.406	0.23*
9.8–10.2	0.034	1	0.023	-0.039	0.085	-0.19*
10.2–10.6	0.016	0	0.000	0.000	0.000	-1.00
Upper Mainstem						
7.4–8.2	0.022	0	0.000	0.000	0.000	-1.00
8.2–8.6	0.092	1	0.031	-0.040	0.103	-0.52*
8.6–9.0	0.298	17	0.531	0.326	0.736	0.45
9.0–9.4	0.330	10	0.313	0.122	0.503	-0.04*
9.4–9.8	0.169	3	0.094	-0.026	0.213	-0.33*
9.8–10.2	0.063	1	0.031	-0.040	0.103	-0.35*
10.2–10.6	0.026	0	0.000	0.000	0.000	-1.00
Ongivinuk						
7.4–8.2	0.005	0	0.000	0.000	0.000	-1.00
8.2–8.6	0.004	0	0.000	0.000	0.000	-1.00
8.6–9.0	0.142	0	0.000	0.000	0.000	-1.00
9.0–9.4	0.500	5	1.000	1.000	1.000	1.00
9.4–9.8	0.259	0	0.000	0.000	0.000	-1.00
9.8–10.2	0.059	0	0.000	0.000	0.000	-1.00
10.2–10.6	0.032	0	0.000	0.000	0.000	-1.00
Total Study Area						
7.4–8.2	0.020	0	0.000	0.000	0.000	-1.00
8.2–8.6	0.055	1	0.013	-0.033	0.058	-0.64*
8.6–9.0	0.262	28	0.350	0.154	0.546	0.21*
9.0–9.4	0.414	36	0.450	0.246	0.654	0.07*
9.4–9.8	0.177	13	0.163	0.011	0.314	-0.05*
9.8–10.2	0.050	2	0.025	-0.039	0.089	-0.34*
10.2–10.6	0.022	0	0.000	0.000	0.000	-1.00
Total		80				

Positive values indicate a preference for that habitat based on proportion to availability, 0 indicates use in proportion to availability (neutral), and negative values indicates avoidance of that habitat ($\alpha = 0.05$). *Indicates that the result was not statistically significant.

References

ADFG (Alaska Department of Fish and Game). 2018. Emergency orders and news releases. Kenai River king salmon limited to catch-and-release.

Anderson, C. 2009. Estimation of Chinook Salmon distribution and run timing in the Togiak River watershed using radio telemetry. USFWS.

Anderson, C. 2010. Estimation of Chinook Salmon distribution and run timing in the Togiak River watershed using radio telemetry. USFWS.

Bell, M. 1986. Fisheries handbook of engineering requirements and biological criteria. Portland, Oregon: U.S. Army Corps of Engineers.

Brunke, M., and T. Gonser. 1997. The ecological significance of exchange processes between rivers and groundwater. Freshwater Biology, 37:1–33.

Chasco, B., I.C. Kaplan, A. Thomas, A. Acevedo-Gutiérrez, D. Noren, M.J. Ford, M.B. Hanson, J. Scordino, S. Jeffries, S. Pearson, K.N. Marshall, E.J. Ward. 2017. Estimates of Chinook salmon consumption in Washington State inland waters by four marine mammal predators from 1970 to 2015. Canadian Journal of Fisheries and Aquatic Sciences 74(8): 1173–1194.

Crozier, L. 2016. Impacts of climate change on salmon of the Pacific northwest. Seattle, Washington: NOAA.

Dugdale, S., N. Bergeron, and A. St-Hilaire. 2013. Temporal variability of thermal refuges and water temperature patterns in an Atlantic salmon river. Remote Sensing of Environment 136:358–373.

Dye, J., and C. Schawnke. 2012. Report to the Alaska Board of Fisheries for the recreational fisheries of Bristol Bay, 2010-2012. ADFG.

Elison, T., P. Salomone, T. Sands, G. Buck, K. Sechrist, and D. Koster. 2018. 2017 Bristol Bay management report. Fishery Management Report No. 18-11. ADFG.

Estensen, J.L., H.C. Carroll, S.D. Larson, C.M. Gleason, B.M. Borba, D.M. Jallen, S.K. Decker, A.J. Padilla, and K.M. Hilton. 2018. Annual management report Yukon Area, 2016. ADFG Fishery Management Report No. 18-14.

Geist, D., and D. Dauble. 1998. Redd site selection and spawning habitat use by fall Chinook Salmon: The importance of geomorphic features in large rivers. Environmental Management 22(5):655–669.

Gilhousen, P. 1990. Prespawning mortalities of sockeye salmon in the Fraser River system and possible causal factors. Vancouver, B.C.: International Pacific Salmon Fisheries Commission. Retrieved from http://www.psc.org/download/48/ipsfc-bulletins/2392/ipsfcbulletinxxvi.pdf

Groot, C., and L. Margolis. 1991. Pacific salmon life histories. Vancouver: UBC Press.

Hamann, E., B. Kennedy, D. Whited, and J. Stanford. 2013. Spatial variability in spawning habitat selection by Chinook Salmon (*Oncorhynchus tshawytscha*) in a wilderness river. River Research and Applications 30(9):1099–1109.

Heard, W.R., E. Shevlyakov, O.V. Zikunova, R.E. McNicol. 2007. Chinook Salmon – Trends in abundance and biological characteristics. North Pacific Anadromous Fish Commission Bulletin No. 4:77–91.

Hetrick, N., K. Simms, M. Plumb, J. Larson. 2004. Feasibility of using video technology to estimate salmon escapement in the Ongivinuk River, a clear-water tributary of the Togiak River. USFWS.

Jacobs, J. 1974. Quantitative measurement of food selection: a modification of the forage ratio and Ivlev's electivity index. Oecologia 14(4):412–417.

Johnson, B., B. Kemp, and G. Thorgaard. 2018. Increased mitochondrial DNA diversity in ancient Columbia River basin Chinook Salmon *Oncorhynchus tshawytscha.* PLOS ONE, 13(1).

Klett, K., C. Torgersen, J. Henning, and C. Murray. 2013. Spatial consistency of Chinook Salmon redd distribution within and among years in the Cowlitz River, Washington. North American Journal of Fisheries Management 33(3):508–518.

Manly, B., L. McDonald, and D. Thomas. 1993. Resource selection by animals: Statistical design and analysis for field studies. London, UK, Chapman and Hall.

Mertes, L. 2002. Remote sensing of riverine landscapes. Freshwater Biology 47(4):799–816.

Mueller, R. 2005. Deepwater spawning of fall Chinook Salmon (*Oncorhynchus tshawytscha*) near Ives and Pierce Islands of the Columbia River. 2004–2005 Annual Report. Project No. 199900301.

Quinn, T.P., and D.J. Adams. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology *77*(4):1151–1162.

Quinn, T.P., A.P. Hendry, and G.B. Buck. 2001. Balancing natural and sexual selection in sockeye salmon: interactions between body size, reproductive opportunity and vulnerability to predation by bears. Evolutionary Ecology Research 3:917–937.

Quinn, T.P., M.J. Unwin, and M.T. Kinnison. 2000. Evolution of temporal isolation in the wild: genetic divergence in timing of migration and breeding by introduced Chinook Salmon populations. Evolution 54(4):1372–1385.

Quinn, T. P. 2005. Behavior and ecology of Pacific Salmon and trout. Vancouver: UBC Press.

Sands, T. 2012. Overview of the Bristol Bay salmon fishery 2010-2012, a report to the Alaska Board of Fisheries. ADFG.

Sethi, S., and T. Tanner. 2014. Spawning distribution and abundance of a northern Chinook Salmon population. Fisheries Management and Ecology 21(6):427–438.

Swaim, M. 2013. Stream temperature monitoring on Togiak National Wildlife Refuge, Alaska 2001–2012. Dillingham, Alaska: USFWS.

Swales, S. 2006. A review of factors affecting the distribution and abundance of rainbow trout (*Oncorhynchus mykiss* Walbaum) in lake and reservoir systems. Lake and Reservoir Management 22(2):167–178.

Tanner, T., and S. Sethi. 2011. Estimation of Chinook Salmon escapement, distribution and run timing in the Togiak River watershed using radio telemetry. Anchorage, Alaska: USFWS.

Tanner, T., and S. Sethi. 2014. Estimation of Chinook Salmon escapement, distribution and run timing in the Togiak River watershed using radiotelemetry, Togiak National Wildlife Refuge, Alaska, 2012. Anchorage, Alaska: USFWS.

Torgersen, C., R. Gresswell, and D. Bateman. 2004. Pattern detection in stream networks: quantifying spatial variability in fish distribution. In Second International Symposium on GIS/Spatial Analyses in Fishery and Aquatic Sciences:405–420.

Torgersen, C., D. Price, H. Li, and B. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of Chinook Salmon in Northeastern Oregon. Ecological Applications 9(1):301.

USFWS (U.S. Fish and Wildlife Service). 2009. Comprehensive conservation plan Togiak National Wildlife Refuge. Anchorage, Alaska.

Visser, R. 2000. Using remotely sensed imagery and GIS to monitor and research salmon spawning. a case study of the Hanford Reach fall Chinook (*Oncorhynchus tshawytscha*). Pacific Northwest National Laboratory.

Vronskiy, B. 1972. Reproductive biology of the Kamchatka River Chinook Salmon [*Oncorhynchus tshawytscha* (Walbaum)]. Journal of Ichthyology 12:259–273.

Weber Scannell, P. 1992. Influence of temperature on freshwater fishes: a literature review with emphasis on species in Alaska. ADFG Habitat Division.

White, G., and R. Garrott. 1990. Analysis of Wildlife Radio-Tracking Data. London, NW: Academic Press.

General Conclusion

Chinook Salmon in the Togiak River experience a range of challenging conditions, including a wide range of temperatures, changing water levels, and various methods of exploitation. For example, in 2010, water levels were higher compared to previous and subsequent years, and the spawning distribution of adults shifted from more fish using the lower mainstem for spawning, to more fish utilizing the upper mainstem reaches and tributaries for spawning (Sethi and Tanner 2014). In addition to fluctuating water levels, fish may also have been exposed to thermal stress, which has been documented at temperatures as low as 15°C (Weber Scannell 1992) for Chinook Salmon. Based on temperature loggers, Chinook Salmon migrating to their spawning grounds and during spawning may experience temperatures as high as 23.4°C within the Togiak River watershed (Swaim 2013). Furthermore, Chinook Salmon in the Togiak River are susceptible to extended periods of fishing pressure by both subsistence and sportfish harvest in the lower mainstem with a potential exploitation rate for Chinook Salmon from 36 to 55% (Sethi and Tanner 2014). These exploitation rates may be especially harmful to early-run fish that may not be as abundant as mainstem spawning fish.

Spawning distribution and environmental correlates are one important portion of Chinook Salmon life history, and this study demonstrated the feasibility of using object-based image classification for understanding habitat in remote Alaskan rivers at the northern extent of their range. Further, the study increased our understanding of environmental correlates of Chinook Salmon spawning locations in the Togiak River drainage. This project's success relied on a field crew that was already in place working on the Togiak Chinook Salmon tagging project. Without this field crew, project logistics would have been considerably more challenging. The major findings of this study were (1) optical imagery was successfully used to classify spawning habitats into three primary (runs, riffles, pools) and two secondary classes (shadows and shallow water), and Chinook Salmon showed a preference for spawning in runs; and (2) thermal imagery was successfully used to classify the temperature range that Chinook Salmon used for spawning, and 96% of Chinook Salmon spawned in water temperatures of 8.6–9.8°C.

The low overall accuracy result could be improved if misclassified objects were reclassified into the correct habitat class. However, one of the primary purposes of this study was to determine how well object-based classification worked on a larger-scale remote sensing project in the riverine environment. Extensive time was spent developing a rule set that would yield the best results possible. Familiarity with the study area allowed me to easily identify misclassified objects that may not have been identified by other researchers. In the future, post hoc corrections could be made to improve the understanding of the relationship between habitat availability, Chinook Salmon spawning locations, and their relationship. A primary advantage of object-based image analysis versus pixel-based image analysis, is that classification categories are broken down into objects more similar (natural) to what the human eye interprets.

Although this study provided an understanding of the environmental correlates of Chinook Salmon spawning habitat, many research priorities remain. These priorities may include long-term monitoring of thermal conditions in the Togiak River drainage and beyond, because southwest Alaska is predicted to rapidly increase in temperature in the future. Because temperature is very important for Chinook Salmon, it would be beneficial to do multiple FLIR surveys to allow fluctuations in water temperatures to be observed throughout the migration or spawning season between years. A single flight, like the one conducted for this study, only provides a brief snapshot of the temperatures Chinook Salmon are experiencing at that moment in time, and it would also be interesting to determine if in subsequent years, the tributary water temperatures continue to be warmer than the mainstem sections. Finally, there were spawning locations that were close to vegetated bars that were not connected by either upstream and/or downstream flow that could be connected in higher water years and were therefore excluded from the proximity analysis in this study. I believe that in higher water years, more spawning locations would be near these areas especially in a run-dominated system like the Togiak River. Unfortunately, southwest Alaska is one of the fastest warming regions and its aquatic resources are at risk from a changing climate and this study provided important information on the current conditions of habitat and water temperatures in the Togiak and Ongivinuk rivers.

References

Sethi, S., and T. Tanner. 2014. Spawning distribution and abundance of a northern Chinook Salmon population. Fisheries Management and Ecology 21(6):427–438.

Swaim, M. 2013. Stream temperature monitoring on Togiak National Wildlife Refuge, Alaska 2001–2012. Dillingham, Alaska: USFWS.

Weber Scannell, P. 1992. Influence of temperature on freshwater fishes: a literature review with emphasis on species in Alaska. ADFG Habitat Division.

Appendix A

UNIVERSITY OF ALASKA FAIRBANKS

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Institutional Animal Care and Use Committee

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April 3, 2012

To:	Andrew Seitz Principal Investigator
From:	University of Alaska Fairbanks IACUC
Re:	[309161-2] Habitat Use and Genetic Analysis of Main Stem and Tributary Spawning Chinook Salmon in the Togiak River, Alaska

The IACUC reviewed and approved the Revision referenced below by Designated Member Review.

Received:	March 22, 2012
Approval Date:	April 3, 2012
Initial Approval Date:	April 3, 2012
Expiration Date:	April 3, 2013

This action is included on the March 27, 2012 IACUC Agenda.

The PI is responsible for acquiring and maintaining all necessary permits and permissions prior to beginning work on this protocol. Failure to obtain or maintain valid permits is considered a violation of an IACUC protocol, and could result in revocation of IACUC approval.

The PI is responsible for ensuring animal research personnel are aware of the reporting procedures on the following page.